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RUFORUM Capacity Building in Agriculture

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Community Action Research Project

RUFORUM SAFFLOWER CARP- GRANT NUMBER RU/2019/CARP+/02

Enhancing safflower production and product development for food security and improving incomes of small-scale farmers in Botswana.

FINAL REPORT: FROM SEPTEMBER 2019 TO DECEMBER 2024.

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Figure 1. Showing training of stakeholders (A, B & C) and some safflower products developed (D, E, & F).

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PROJECT SUMMARY

Safflower (*Carthamus tinctorius* L.) is a member of the Compositae or Asteraceae family, cultivated mainly for its seed, which is used to extract high-quality edible oil consisting of mono-and poly-unsaturated fatty acids (oleic, linoleic and linolenic), livestock and poultry feed, vegetables, cut flowers, birdseed or for its flowers, used as dye sources for textiles, colouring foods, cosmetics, textiles and pharmaceuticals, and medicinal purposes. The safflower petals (flowers) have the potential for the manufacture of plant-made pharmaceuticals. Compared to other oilseed crops, safflower has remained a minor, underutilized, and neglected crop. Despite its adaptability to diverse growing conditions, high yield potential, and varied uses for different plant parts, safflower has received little research attention. On the positive side, currently interest in safflower production has increased due to low edible oilseed production in countries with considerable low rainfall, consumer preferences for healthy vegetable oils with lower saturated fats, medicinal uses of flowers, extraction of edible natural dyes from flowers to be used in food, pharmaceutical, and cosmetics colouring, and have become more widely known and increased demand of vegetable oil for biodiesel. Safflower is a drought, heat, cold and saline tolerant crop. It is the most drought tolerant oilseed crop and can produce good seed yield in arid and semi-arid lands (ASALs). Its salt tolerance ability is an asset as the area affected by some degree of salinity continues to increase world-wide due to low unpredictable precipitation and high evapotranspiration induced by climate change. Safflower also tolerates a wide range of temperatures from -15 to 40°C, provided there is no frost during the elongation and flowering phases of growth and development. Biotic and abiotic stresses are the factors limiting agricultural productivity most. However, drought stress and salinity are the most important limiting factors to crop production in agricultural systems in the ASALs including Botswana. Therefore, the overall objective of this project was to enhance safflower production and product development with the goal to mitigate the effects of climate change, improve food and nutrition security, social welfare, disposal income of farmers and other stakeholders, and build capacity in the safflower value chain using multisector approach. While the specific objectives were to evaluate on-farm: 1) safflower genotypes performance for morphological characteristics, seed yield and yield components, oil yield, and fatty acid composition of the oil grown under on-farm in four growing sites; 2) safflower nitrogen and phosphorus requirements in different soils under on-farm trials in three growing sites; 3) safflower genotypes

suitable for petal production and time of harvesting on petal and seed yield, carthamin and carthamidin content in three growing sites; 4) insect pest status, population dynamics and their natural enemies plus beneficial insects on five safflower genotypes in three growing sites both in winter and summer; 5) effects of nitrogen fertilizer application on safflower insect pest population dynamics, their natural enemies and beneficial insect; 6) effects of temperature, duration of exposure, and phenological stages on the incidence and severity of chilling injury of safflower; 7) Link the university and TVET institutions; and 8) train farmers in safflower growing, processing, product development and marketing.

The outputs of this project include 1) networks and capacity in safflower research, both small-scale and commercial production, product development, extension, marketing, and entrepreneurship with various stake holders including policy makers and investors have been built. For example, 4 PhD and 4 MSc students, 10 TVET students, and 1800 farmers have been trained in safflower research and product development. 1800 farmers have been trained in safflower production, product development, marketing, and entrepreneurship; 2) This safflower CARP project has generated scientific information on the physiology, phenology, agronomy, fatty acid composition, processing and value addition of safflower that will enable its commercialization. Four PhD theses, 4 MSc theses, 2 book chapters, 10 papers in peer reviewed journals with impact factors, 17 conference papers, 3 videos, and 6000 extension brochures to date have been published through the research generated under this CARP project; 3) Further funding in safflower research was obtained from the Department of Agricultural Research (Ministry of Agricultural Development and Food Security) from the Japan International Co-operation Agency (JICA) and Government of Botswana (GoB) for the sponsorship of 2 PhD students; 4) The multilocation trails led to the selection of safflower genotypes with stable seed yield, oil content, and composition for Botswana conditions. This led to the soon (December 2024) release of 8 safflower cultivars. The Cultivars that are to be released by The Botswana of Agriculture and Natural Resources (BUAN) include Kiama Composite, PI 407616 BJ-213 Turkey, PI 537598 SINA USA, PI 30441 BJ-2621 Iran, PI 5376321038-USA, PI 314650 MILUTIN 114 Kazakhstan, PI 537634-1040-USA, and PI 537668-BJ-1085-USA; 4) This project has also promoted and created awareness of safflower as a drought tolerant crop to farmers, government extension system and policy makers, NGOs and community-based organizations (CBOs), traders and the formal seed sector (Seed-Co); 5) This project empowered farmers. The safflower CARP project empowered 168 women who suffered gender-based violence (GBV) during COVID-19 lockdowns. The Rakops women's group have registered a co-operative under the Botswana Society Act called "Saff Energy Initiative Multipurpose Co-operative Society". The safflower project has significantly improved the social status and disposal income of these vulnerable women that suffered GBV. Other co-operatives that were formed through the mentorship of the research team that grow, develop and sell safflower products include The Kweneng North Horticultural Co-operative Society, African Entrepreneurial Development Agency, and Letsema Co-operative Society. Lead farmers were also empowered through training and became trainers of other farmers at a fee; 6) Promotions and employment. The safflower CARP gave opportunities for lecturers to be supervisors for MSc and PhD students which fed into their key performance areas of research and outreach. Due to research generated publications (MSc and PhD Theses, videos, and papers in refereed journals) and outreach to the community through the safflower CARP, the Co-PI and one other Supervisor were promoted from Senior Lecturer to Associate Professor and Lecturer to Senior Lecturer, positions. All students trained under the safflower CARP project (3 PhD and 4 MSc) are employed by the MoA, except for the one who is finishing her PhD research; 7) Linkages and BUAN visibity. The safflower CARP project created opportunities for multi-disciplinary research and collaboration across departments and faculties within BUAN, between universities and other universities (national and regional), and national research institutions. This CARP project, through on-farm research and training of farmers, field days, and workshops also established much stronger links between the university and the farming community. The safflower CARP further improved the visibility of BUAN nationally, regionally, and internationally through outreach and/or extension services, research outputs published in journals and book chapters with impact factors, development, and linkages with government agencies and policymakers; 8) Mitigating effects of climate change. The growing of safflower in Botswana is mitigating the effects of climate change, and food and nutrition insecurity caused by low unpredictable rainfall and poor soils because it grows under rainfed conditions in sodic and infertile soils. Safflower production has improved food and nutrition security, reduced reliance on food imports, and improved income levels of farmers in Botswana through the sale of safflower products such as cooking oil, petals, cut-flowers, vegetable, seed, roughage, and meal. Safflower has also improved the livestock sub-sector through the availability of feed and reduced the import bill of livestock feed and vegetables. Safflower cooking oil has the potential to replace imports of olive oil in high-end stores and to provide healthy cooking oil when its extraction is scaled up by farmers and other investors or stakeholders; 9) Change in government of Botswana policy. The Ministry of Agricultural Development and Food Security (MoA) changed its policy on the Integrated Support Program for Arable Agriculture Development (ISPAAD) and developed a new policy called Temo-Letlotlo program. Safflower is one of the 13 crops supported by this program; and 10) Dissemination and communication. Results of the safflower CARP project have been disseminated and communicated to different stakeholders consisting of farmers, extension officers, government parastatals, researchers, policy makers, financial institutions, non-governmental organizations involved in agricultural development, private seed companies, private sector, and the scientific community. In conclusion, this project implemented and achieved all its set objectives. The research team recommended that local and sustainable seed systems to enable a regular supply of reasonably clean seed needs to be developed. Individual farmers, farmer groups, businesspeople or local institutions with the necessary resources need to be trained as specialized and commercial seed producers. Therefore, the research team requests RUFORUM to fund this phase of the project.

Keywords: Safflower, *Carthamus tinctorius* L., Community action research, Capacity building, Product development, Climate change mitigation

CHAPTER 1

1.0 Introduction

Safflower (*Carthamus tinctorius* L.) is a temperate crop that is cultivated in arid and semi-arid lands (ASALs) of the world (McPherson et al., 2004; Emongor, 2010; Janmohammadi, 2015; Emongor et al., 2017a). Safflower is an underutilized, neglected, and minor crop compared to other oilseed crops despite its excellent adaptability to various climatic conditions, tolerance to drought, salinity and extreme temperatures, and the seeds containing essential fatty acids (oleic and linoleic) which are beneficial to human health (Emongor & Emongor, 2023; Mani et al., 2020; Moatshe et al., 2020a; Marang et al., 2022; Emongor & Emongor, 2023; Emongor et al., 2017b). Global warming is predicted to increase the frequency of droughts, floods, and heatwaves (IPCC, 2021). The rise in global temperatures may cause climate anomalies, resulting in crops encountering increasing abiotic and biotic stress combinations, which may negatively influence their growth, development, and yield (Mahalingam, 2015; Marang et al., 2022; Emongor & Emongor, 2023). The use of suitable crop species such as safflower (Figures 2, 3, 4,5) and variety of cropping systems should be adopted in response to climate change (Acevedo et al., 2020; Hufnagel et al., 2020; Marang et al., 2022).

Figure 2. Safflower at end of the rosette stage, Morwa Botswana July 2021.

Figure 3. Safflower at the elongation phase, Morwa Botswana August 2021.

Figure 4. Safflower at the flowering stage Morwa Botswana, October 2021.

Figure 5. Ministry of Agriculture Extension Saff visiting Morwa Safflower Farmer (Left with red T-shirt) Botswana End of July 2021.

Drought stress causes reduced crop height, biomass and yield. The quantity of available water to a crop is an important factor that determins yield. Drought negatively affects the already fragile food and agricultural situation in ASALs and impairs rural economies and socio-cultural structures. Due to erratic, unreliable, and poorly distributed rainfall, incombination with high temperatures (43°C) and evapotranspiration rate (1800-3000 mm per annum), water becomes the most restricting factor to agricultural production in Botswana and other ASALs (Emongor, 2009; Farooq et al., 2009). Climate change is worsening rainfall unreliability and distribution in Botswana and other ASALs (Mittler & Blumwald, 2010; IPCC, 2021; Habib-ur-Rahman et al., 2022; Emongor & Emongor, 2023). Botswana is already vulnerable to drought and likely to worsen with climate change. Therefore, it is important to research crops that are less dependent on regular rains and tolerant to salinity and extreme temperatures enhanced by climate change.

1.2 Problem Statement

The agriculture sector in Botswana is important because of the multiple backward and forward linkages to other sectors of the economy such as input services, transport, manufacturing, advisory services, financial services, and tourism. Consequently, when agriculture thrives, the rest of the economy will prosper. The sector's contribution to GDP declined from 80% in 1966 at independence to 1.99 % in the current period (Statistics Botswana 2017). This is due to stagnation of the sector and growth of other sectors especially mining and tourism. In addition, Botswana experiences low rainfall (250-650 mm per annum depending on season), and high temperatures and evapotranspiration rate 1800-3000 mm per annum) making it a water deficit country by virtue of its location in the sub-tropical high-pressure belt of the southern hemisphere in the interior of Southern Africa and away from oceanic influence (Emongor, 2009). The national vision of Botswana referred to as Vision 2036 envisions agriculture as the one to drive a sustainable technology and commercially viable economy (NDP 11). In the current strategy, the vision of the

Ministry of Agricultural Development and Food Security in Botswana is to attain national food security and global competitiveness in agricultural production. With the mission to improve agricultural productivity through technology development and transfer, diversification, and commercialization, to promote food security in partnership with stakeholders. The development of private sector-led value chains in the agricultural sector including production, processing, marketing, and distribution activities will become possible when high value crops such as safflower are integrated into the cropping system in Botswana.

Due to the erratic, unreliable, and poorly distributed rainfall, plus high temperatures, water is the most limiting factor to agricultural production in Botswana (Emongor, 2009). Traditionally grown staple crops such as sorghum, cowpeas, pearl millet, beans, and maize experience low yield and frequent crop failures. Therefore, the total food produced does not meet the demands of the country. This food shortfall is met through imports. For example, in January 2022, Botswana's total imports were valued at US$ 693,282,881 (Statistics Botswana, 2022). Of this amount, food imports constituted 12.2 percent. Safflower cultivation in Botswana is ideal as it has potential to diversify the economy, commercialise production and bridge the gap of edible oil, livestock feed, vegetables, and herbal teas shortage in the country in the short term. In the long term Botswana can produce pharmaceuticals for the treatment of cardiovascular, cerebrovascular, vascular, cancer, and gynaenocological diseases plus drugs for nervous and immune systems complications (More et al., 2005; Han et al., 2016; Li et al., 2016; Ao et al., 2018; Hu et al., 2019; Jin et al., 2019; Ma et al., 2019; Qu et al., 2019; Zhang et al., 2019; Chen et al., 2020; Mani et al., 2020; Ye et al., 2020; Emongor & Emongor, 2023). This safflower CARP project was envisioned to explore the potential for safflower in Botswana because of its tolerance to limiting abiotic factors (low rainfall and saline soils and underground water caused by aridity) present in the country. Therefore, growing a multipurpose, drought, saline and extreme temperature tolerant crop such as safflower in Botswana was expected to: 1) mitigate the effects of climate change in a semi-arid country such as Botswana; 2) improve food security, reduce reliance on food imports and improve income levels of farmers in Botswana through the sale of safflower products such as oil, processed petals, cut-flowers, vegetables and cake after oil extraction for livestock feed, hence reduction in poverty and hunger; 3) improve the livestock sub-sector through the availability of feed (seeds, cake, direct grazing, hay and silage) hence reduction in feed importation, increased farmer income, reduction in poverty and hunger; and 4) improve health and well-being of Batswana of all ages through use of safflower oil in cooking, salad dressings, and making baby foods which has plenty of health benefits due to the polyunsaturated and monounsaturated linoleic and oleic fatty acids, respectively. However, introducing a new crop to a regional cropping system requires information on its performance under local agronomic and environmental conditions. This is the knowledge gap this CARP project intended to fill, and it was filled.

1.3 Associated Projects.

This project was upscaling of an earlier project (GRG 106) funded by The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) which involved safflower (*Carthamus tinctorius* L.) germplasm evaluation for Botswana Conditions financed to the tune of US $ 60,000. The project was successfully implemented. Two Master of Crop Science (Horticulture) students were trained which built capacity in agricultural research and extension in Botswana. One of the trained MSc student is the current District Agricultural Coordinator Central District. The other MSc trained student is undertaking her PhD studies in BUAN. The other outcomes of the project were a national stakeholders workshop was held which involved participation of policy makers, extension officers, 24 farmers, researchers (University of Botswana, Botswana International University of Science and Technology, Botswana University of Agriculture and Natural Resources, Department of Agricultural research, National Food Technology Research Centre) and private sector and members of media. The stakehoders workshop created awareness and disseminated information about safflower production and products (vegetable, cut-flower, seed, cooking oil, safflower tea, cake for livestock feed). Safflower information was disseminated through radio and newspaper publications. This led to the adoption of safflower by Batswana farmers and it created a high demand for safflower seed. The other ouputs were safflower production book (ISBN 978-99968-0-607-0), extension pamphets (1000), two MSc theses and three manuscripts were published in peer reviewed journals.

Due to the successful dissemination of safflower information including the uses and products developed, it created a high demand for seed which the Botswana University of Agriculture and Natural Resources (BUAN) and the Department of Agricultural Research (DAR) Ministry of Agricultural Development and Food Security are currently multipying safflower seed in two sites in trying to meet the demand for seed. This called for the private sector (seed companies and farmer associations) involvement. Therefore, this CARP project sought to upscale the earlier safflower project to involve farmers or farmer associations to be involved in seed multiplication, production, oil extraction, production and packaging of safflower tea, production of livestock feed and feed supplements, and marketing of safflower products.

1.3.1 Safflower enterprise diversification

In a cereal-based enterprise, safflower can provide a hedge against unpredictable weather. Because safflower can be planted later than cereals, it can be substituted for part of the cereal crop if planting rains begin too late for cereals in Botswana. A large amount of rain during cereal sowing and harvest can be detrimental to these crops but may benefit safflower because it can be grown all year round in Botswana. This allows for a more diversified cropping program, which has several advantages. For example, the later sowing and harvest of safflower spreads seasonal workloads and may reduce the exposure of crops to frost, and the incorporation of another crop species increases the opportunity to rotate herbicide groups. Safflower's ability to be grown all year round can help to mitigate effects of climate change and on the whole-farm budget of late rain failure losses to cereals, thereby reducing risk.

1.4 Project Objectives

1.4.1 Main objective

To enhance safflower production and product development with the goal to mitigate the effects of climate change, improve food and nutrition security, social welfare, disposal income of farmers and other stakeholders, and build capacity in the safflower value chain using multisector approach.

1.4.2 Specific objectives

The specific objectives of this project were to evaluate on-farm:

1) safflower genotypes performance for morphological characteristics, seed yield and yield components, oil yield, and fatty acid composition of the oil grown under on-farm in four growing sites.

2) safflower nitrogen and phosphorus requirements in different soils under on-farm trials in three growing sites.

3) safflower genotypes suitable for petal production and time of harvesting on petal and seed yield, carthamin and carthamidin content in three growing sites.

4) insect pest status, population dynamics and their natural enemies plus beneficial insects on five safflower genotypes in three growing sites both in winter and summer.

5) effects of nitrogen fertilizer application on safflower insect pest population dynamics, their natural enemies and beneficial insect.

6) effects of temperature, duration of exposure, and phenological stages on the incidence and severity of chilling injury of safflower.

7) Link the university and TVET institutions

8) Train farmers in safflower growing, processing, product development and marketing.

1.5 Project Conceptual Framework

Once RUFORUM approved the safflower CARP project in June 2019, the Botswana University of Agriculture and Natural Resources (BUAN) began project implementation with a consortium of partners and institutions from the public and private sectors working with farmer groups, individual farmers, and community-based organizations. BUAN was the lead institution in the partnership working with the Department of Agricultural Research (DAR) and Extension Staff in the Ministry of Agricultural Development and Food Security, Ministry of Youth and Gender, University of Botswana, Botswana International University of Science and Technology, Kgatleng

Brigades (TVET Institution), National Food Technology Research Centre, African Entrepreneurial Agency, the Healthy Families Foundation, Farmer Groups, and Individual Farmers. The project team members and collaborators had different expertise that fitted well with the research objectives. Mentorships were both provided by the team members of the project and stakeholders who had been working with safflower and the localities where the project was implemented. The project was implemented in Kgatleng, South-East, Kweneng, Southern, North-East, and Central Districts of Botswana. The Principal Investigator (PI), Co-PI, Participating Researcher, and MSc and PhD students in the CARP project have developed the following products: vegetables, herbal tea, seed, animal feeds (cake, meal, seed, roughage, hay, silage), and cooking oil which have been disseminated to stakeholders and are being produced with an increasing demand for safflower seed.

Project implementation was delayed by COVID-19 pandemic lockdowns. However, for the MSc and PhD students to complete coursework and defend their research proposals blended learning (on-line lectures using Moodle with face-to-face learning for practicals) was introduced. Farmer training was done via WhatsApp. The research approach and conceptual framework for the implementation of the project is shown in Figure 6.

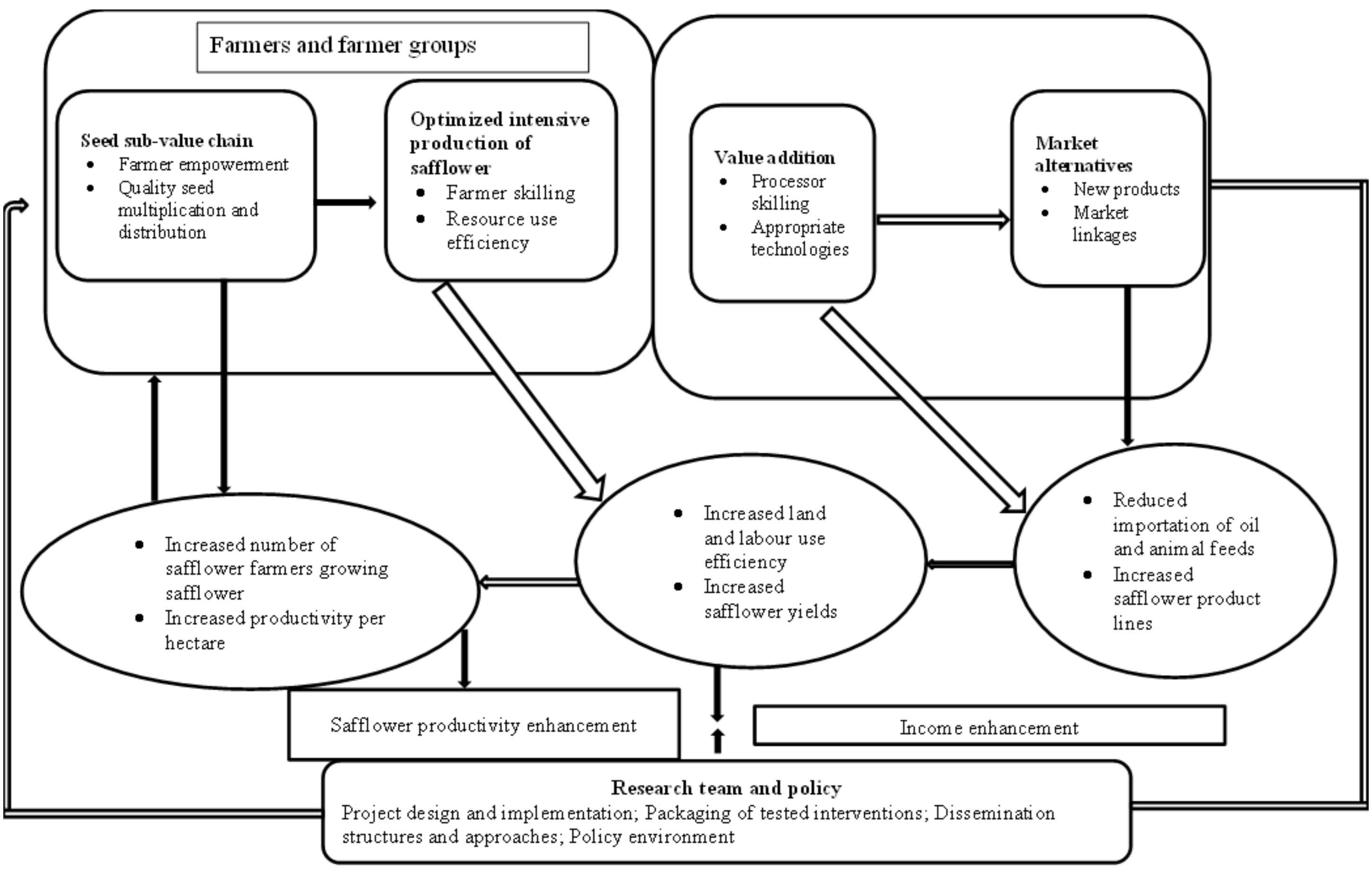


Figure 6: Implementing approach and conceptual framework

1.6 Partners Involved

The project has been implemented by a consortium of partners and institutions from the public and private sectors as well as farmer groups and community-based organizations. Botswana University of Agriculture and Natural Resources (BUAN) was the lead institution in partnership with the Department of Agricultural Research (DAR) and Extension Staff in the Ministry of Agricultural Development and Food Security, Ministry of Youth and Gender, University of Botswana, Botswana International University of Science and Technology, Kgatleng Brigades (TVET Institution), National Food Technology Research Centre, African Entrepreneurial Agency, the Healthy Families Foundation, Farmer Groups, Farmer Co-operatives (Kweneng North Horticultural and Green Diamonds of Botswana) and Individual Farmers. Below is the list of key project partners:

Table 1. Partners involved

I. Researchers and Supervisors			
Number	Name and Institution	Contact	Role
1	Professor Vallantino Emongor, Botswana University of Agriculture and Natural Resources (BUAN)	vemongor@buan.ac.bw or vemongor@gmail.com	PI and Student Supervisor to two PhD and five MSc students.
2	Professor Bamphitlhi Tiroesele, BUAN	btiroese@buan.ac.bw	Co-PI and Student Supervisor to three MSc students.
3	Dr. Onkgoletse Moatshe-Mashiqa, Department of Agricultural Research (DAR), Ministry of Agricultural Development and Food Security	ogmoatshe@gov.bw or moatsheonkgolotse@gmail.com	Participating Researcher and Supervisor to one MSc student.
4	Professor Utlwang Batlang, BUAN	ubatlang@buan.ac.bw	Supervisor to one PhD student.
5	Doctor Goitseone Malambane, BUAN	gmalambane@buan.ac.bw	Supervisor to two PhD students.
6	Doctor Thebweetsile Moroke, BUAN	tmoroke@buan.ac.bw	Supervisor to two MSc students.
7	Doctor Renameditswe Mapitse, University of Botswana	mapitser@ub.ac.bw	Supervisor to one PhD student.
8	Doctor Baghali Mathapa, BUAN	bmathapa@buan.ac.bw	Researcher assisted PhD student in oleosin

			gene expression analysis.
9	Doctor Patrick Mashiqa (DAR)	pmashiqa@gov.bw	Researcher
10	Ms. Maatla Korononeo, BUAN	maatlakagelelo@gmail.com	Project Research Assistant assisted in research activities and project implementation
		II. Students	
11	Ms. Mosupiemang Marang, BUAN	marangmosupiemang@yahoo.com	PhD student worked on objective 1: safflower genotypes performance for morphological characteristics, seed yield and yield components, oil yield, and fatty acid composition of the oil grown under on-farm in four growing sites.
12	Mrs. Dineo Phuduhudu Kereilwe, BUAN	dphuduhu@gmail.com	PhD student worked on objective 6: Effects of temperature, duration of exposure, and phenological stages on the incidence and severity of chilling injury of safflower.
13	Mrs. Keheng, Basiame, Ministry of Agricultural	kbasiame@gmail.com	MSc student worked on

	Development and Food Security, Botswana		objective 4: Insect pest status, population dynamics and their natural enemies plus beneficial insects on five safflower genotypes in three growing sites both in winter and summer.
14	Ms. Kolanyane Opelo Maduo, BUAN	maduoopelokolanyane@gmail.com	MSc student worked on on objective 2: Safflower nitrogen and phosphorus requirements in different soils under on-farm trials in three growing sites.
15	Ms. Bonolo Setshogela, BUAN	bsetshogela91@gmail.com	MSc student worked on objective 3: safflower genotypes suitable for petal production and time of harvesting on petal and seed yield, carthamin and carthamidin content in three growing sites.
16	Mr. Pako Monyame, BUAN	pmonyame@hotmail.com	MSc student worked on objective 6: Effects of nitrogen fertilizer application on

			safflower insect pest population dynamics, their natural enemies and beneficial insect.
III. Extension Officers and Local Community			
17	Mrs. Mpho Morupisi Mogorosakgomo, Ministry of Agricultural Development and Food Security	mmogorosakgomo@gov.bw	Extension officer assisted in organizing farmers for training.
18	Mrs. Phole Oarabile, Ministry of Agricultural Development and Food Security	pholeoarabile@gmail.com	District Agricultural Coordinator assisted in organizing and training farmers
19	Mr. Nelson Mwaniki, Ramoswa and Gaborone	nelsonmwaniki@gmail.com	Lead Farmer assisted in training other farmers
20	Mrs. Sarah Mosarwa, Kweneng District	+26772247384	Lead Farmer assisted in training other farmers
21	Nnyaladzi Madzikigwa, Rakops	madzikigwannyaladzi@gmail.com	Lead Farmer assisted in training and organizing other farmers
22	Jonathan Beesigomwe, African Entrepreneurial Development Agency	aedamsix@gmail.com	Lead NGO assisted in organizing farmers for training
23	Professor Flora Meulenberg, BUAN	fpmeulenberg@buan.ac.bw	Lead Farmer assisted in organizing farmers for training at

24	Matsapa Matsapa, Kgatleng Brigades, Mochudi	+26771550898	Contact Person TVET assisted in recruitment of students in Kgatleng Brigades to fabricate safflower planter

Regarding modifications to project design, stakeholders, partnerships envisaged support to the implementation process, there were no modification to the planned designs, stakeholders, and partnerships for the project. Only that we have admitted an extra PhD student to investigate chilling physiology in safflower. The project team members and collaborators had different expertise that fitted with the research objectives, mentorships were both provided by the team members of the project and stakeholders who were worked in the regions where the project was implemented.

CHAPTER 2

2.0 METHODOLOGY

2.1 Study Sites

The project was implemented in five districts of Central, Kweneng, Kgatleng, North-East, Southern, and South-East.

Central District: Central is the largest of Botswana's districts in terms of area and population. The administrative capital is Serowe. It encompasses the traditional homeland of the Bamangwato people. It borders the Botswanan districts of Chobe, North-West, Ghanzi, Kweneng, Kgatleng, and North-East in the north, northwest, west, southwest, south, and northeast, respectively. It also borders Zimbabwe in the northeast (Matabeleland North and Matabeleland South Provinces) and South Africa in the southeast (Limpopo Province). The district has an average altitude of 1111 m above sea level and located on longitude 26.00 and latitude -22.00. Central district has a total population of 706,135 with a land area of 147,730 km^2 (Statistics Botswana, 2022). The district has an average altitude of 972 m above sea level with average annual precipitation of 505 mm, most of which is received during the summer season from November to May (Botswana Maps, 2024). The vegetation type is savannah, with tall grasses, bushes, and trees. The major economic activities of this district are agriculture, tourism, construction, finance, transport and communication, and mining.

Kweneng District: Kweneng district is the recent historical homeland of the Bakwena people, the first tribe in Botswana to be converted to christianity by famed missionary David Livingstone. Various landmarks, including Livingstone's Cave, allude to this history. The administrative capital of Kweneng district is Molepolole. It borders the following districts Central, Kgatleng, South-East, Southern, Kgalagadi, and Ghanzi in the northeast, east, southeast, south, west, and north, respectively. The population of the district is 387,983 with a land area of 35,890 km^2 (Statistics Botswana, 2022). The district has an average altitude of 1117 m above sea level and located on longitude 25.28375850 and latitude -23.83672490. The vegetation type is savannah, with tall grasses, bushes, and trees. The annual precipitation is approximately 250 mm, most of which is received during the summer season from November to May. Most of the rivers in the region are seasonal, with Metsimotlhabe river, which are prone to flash floods, being the most prominent (Singh, 2011). Manyana rock paintings in Manyana village and Kgosi Sechele I Museum are the major attractions in the district (Government of Botswana, 2024). The major economic activities of this district are agriculture, construction, finance, and tourism.

Kgatleng District: The administrative capital is Mochudi. Kgatleng is the homeland of the Bakgatla people. According to the 2022 census the population of the district was 121,882 with a land area of 7,960 km^2 (Statistics Botswana, 2022). It borders North-West and Limpopo Provinces of the Republic of South Africa in the south and east, respectively. Within Botswana, it borders

South-East, Kweneng, and Central districts in the southwest, west, and north, respectively. The district has an average altitude of 935 m above sea level and located on longitude 25.5°E and latitude 24.25°S. The vegetation type is savannah, with tall grasses, bushes, and trees. The annual precipitation is approximately 500 mm, most of which is received during the summer season from November to May. The major economic activities of this district are agriculture, construction, finance, tourism, and mining.

North-East District: The administrative capital is Francistown. The district borders the Matabeleland South Province of Zimbabwe, and in the east is predominantly along the Ramokgwebana river. In the south and west, the district borders Central district along the Shashe river. The population of the district is 172,769 with a land area of 5,120 km^2 (Statistics Botswana, 2022). The district is predominantly occupied by Kalanga-speaking people, the BaKalanga. The district is administered by a district administration and district council, which are responsible for local administration. The district has an average altitude of 1090 m above sea level and located on longitude 27.4556388 and latitude -20.9030555. The vegetation type is savannah, with tall grasses, bushes, and trees. The annual precipitation is approximately 265 mm, most of which is received during the summer season from November to May. The major economic activities of this district are agriculture, construction, finance, tourism, manufacturing, and mining.

South-East District: The capital city of Botswana, Gaborone is surrounded by this district. The administrative capital is Ramotswa. It borders the North-West Province of the Republic of South Africa. Domestically, it borders Kgatleng, Kweneng, and Southern districts in the northeast, northwest, and southwest, respectively. As of 2022 census, the total population of the district was 387, 537 with a land area of 1,780 km^2 (Statistics Botswana. 2022). The district has an average altitude of 1131 m above sea level and located in longitude 25.8048521 and latitude -24.936609 with average barometric pressure of 88KPa. The vegetation type is savannah, with tall grasses, bushes, and trees. The annual precipitation is about 221 mm, most of which is received during the summer season from November to May. The major economic activities of this district are agriculture, construction, finance, tourism, manufacturing, and mining.

Southern District: The administrative capital is Kanye. Southern district is home to the Bangwaketse and Barolong tribes of Botswana. Southern district is the second largest beef producer after Ghanzi district. Within the district there are large privately owned and government beef ranches. Maize and sorghum, Botswana's staple crop, are also produced in the district. Southern district is where the third diamond mine of Botswana is found (the Jwaneng diamond mine), which buoys Botswana's economic state of prosperity. It was the first district to house the capital city (Kanye) before being moved to Gaborone after independence. The district borders Noth West Province of the Republic of South Africa in the south, and South-East, Kweneng, and Kgalagadi districts of Botswana in the east, north and southwest, respectively. The population of the district is 240,712 with a land area of 28,470 km^2 (Statistics Botswana, 2022). The district has an average altitude of 1191 m above sea level and located on longitude 24.7142918 and latitude

-24.823384. The vegetation type is savannah, with tall grasses, bushes, and trees. The annual precipitation is approximately 220 mm, most of which is received during the summer season from November to May. The major economic activities of this district are agriculture, construction, finance, tourism, manufacturing, and mining.

Figure 7: Districts of Botswana

Most of the research was on-farm by PhD and MSc students who worked with farmers on specific research problems that were identified by the students, farmers, and research team to contribute to the attainment of the above project objectives. Students were registered at The Botswana University of Agriculture and Natural Resources (BUAN). One student was registered at the University of Botswana working on use of plant growth regulators (PGRs) to influence the growth, development, seed and oil yield, and oil content of safflower with the goal to develop high quality biodiesel [(student sponsored by Japanese International Cooperation Agency (JICA)-PI of the safflower CARP was Co-Supervisor)]. Due to large distances from BUAN on-farm research was done in Molepolole (Kweneng district) which lies on latitude 24° 24' 24’S and longitude 25° 29' 42’E elevated at 1149 m above sea level with annual precipitation of 376 mm; Sebele (South-East district) which lies located at an altitude of 994 m above sea level and latitude of 24°33’ South and a longitude of 25°54’ East with average annual rainfall of 650 mm; Ramonaka (Kgatleng district) which lies on latitude 24.19704450 S and longitude 26.23046160 E with an elevation of 936.25 m above sea level with mean annual precipitation of 255 mm; Metsimotlhabe (Kweneng district) which lies on latitude 24.5530556 S and longitude 25.80388890 E with an elevation of 997.62 m above sea level with mean precipitation of 250 mm; and Rakops (Central district) which lies on latitude 21° 3’ 0” S and longitude 24° 25’ 0” E with an elevation of 917 m above sea level and average annual precipitation of 339 mm. The soil at Rakops was calcaric regosols with physical units being solonchaks which are strongly calcareous (saline) and the underground water is very saline due to calcium carbonate.

2.2 Project Inception Meeting

Project inception meeting involved all project team members and key stakeholders including farmers, government, community leaders (Chiefs), institutions of higher learning, research institutions, community-based organizations, TVET institution, and service providers. The meeting served as an initial stage for establishment of the innovation platform comprising different stakeholders in the safflower value chain. The meeting also engaged stakeholders to deliberate on methods of information dissemination on safflower for adoption across the country, prioritise research objectives, develop guideline for admission of MSc and PhD students, and assigning tasks and roles to various actors.

2.3 Students Recruitment

The project had six objectives designed to involve master’s and PhD students as part of capacity enhancement in research. The available training opportunities were advertised through BUAN website and two Botswana newspapers Mmegi and Daily News with the goal to reach a wide audience. Two adverts were done in July 2019 and 2020 for students to come in two cohorts for efficient supervisor. Interested students applied for sponsorship by submitting concept notes of research projects that were aligned to specific research objectives as was specified in the call for applications. Students were selected; first, on the basis of satisfying the admission criteria for master’s and PhD qualifications at BUAN and secondly, on the basis of quality of concept notes that were endorsed by the research team. Below is a sample of the advert.

BUAN
BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES
Inspiring Sustainable Growth

Application for the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) MSc (two) and PhD (one) Scholarships

The Botswana University of Agriculture and Natural Resources in collaboration with the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) invites applications from suitably qualified Batswana Citizens for admission and sponsorship for the Degree of Master of Science and PhD programme in **Crop Science.** The MSc can either be in Crop Protection or Horticulture Streams (one scholarship for each stream). The PhD can either be in agronomy or Horticulture. The duration of the MSc programme is two (2) years on full time basis. While the duration of the PhD programme is three (3) years on full time basis.

MSc Requirements: Candidates must possess a BSc Crop Science (Horticulture or Agronomy) or BSc in Horticulture or Agronomy or Crop Protection or BSc Agriculture with a minimum of 2(i) classification.

PhD Requirements: Candidates must possess MSc Crop Science or MSc Horticulture or MSc Agronomy and must have done Biometry or Statistics including experimental designs. The candidates must be 40 years or less.

Conditions of Scholarship: The successful candidates are required to start the programme in August 2019 on full-time basis and must be willing to do research on safflower (*Carthamus tinctorius* L.) nitrogen and phosphorus mineral nutrition (one student) and insect pest status, population dynamics and their natural enemies in safflower (one student).

Scholarship Coverage: The scholarship shall cover tuition fees, research expenses, living allowance, medical insurance, book allowance, laptop and cost of thesis binding.

Method of Application: The application letter must be accompanied by CV, three references, certified copies of educational certificates, grade transcripts, and a copy of national identity card. **Applicants must include an acceptable preliminary and typed research proposal of not more than 500 words** based **on one the research topics above.** Applicants must pay a non-refundable application fee of P150.00.

The application form for the programme is obtainable from the University Admissions office Block 302 Room 002 or can be downloaded at www.buan.ac. bw.

Further information on the programme and scholarship can be obtained from: Principal Investigator or Participating Researcher Department of Crop and Soil Sciences (*Email mobopile@buan.ac.bw or vemongor@buan.ac.bw or vemongor@gmail.com*), Telephone **(267) 3650207, Cell 72709174,** (Fax **(267) 3928753.**

The application must be submitted to: The Director Academic and Student Services,

Botswana University of Agriculture and Natural Resources, P/Bag 0027, Gaborone, Botswana

Closing date**: 25th July 2019.**

2.4 Baseline Study

This project was upscaling of an earlier project (GRG 106) funded by The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) which involved safflower (*Carthamus tinctorius* L.) germplasm evaluation for Botswana conditions. Basic and applied research was done since 2008 to 2014 in BUAN but the crop (safflower) or technonology was not disseminated to the farmers. Therefore, no baseline study was undertaken because safflower was a new crop in Botswana and no farmers were growing it. The objective of the research team and the relevant stakeholders was to introduce safflower into the cropping of Botswana, enhance its production and product development with the goal to mitigate the effects of climate change, improve food security and build capacity in the safflower value chain using multisector approach.

Once RUFORUM approved the safflower CARP project in June 2019, the Botswana University of Agriculture and Natural Resources (BUAN) began project implementation with a consortium of partners and institutions from the public and private sectors working with farmer groups, individual farmers, and community-based organizations. BUAN was the lead institution in the partnership working with the Department of Agricultural Research (DAR) and Extension Staff in the Ministry of Agricultural Development and Food Security, Ministry of Youth and Gender, University of Botswana, Botswana International University of Science and Technology, Kgatleng Brigades (TVET Institution), National Food Technology Research Centre, African Entrepreneurial Agency, the Healthy Families Foundation, Farmer Groups, and Individual Farmers. The project team members and collaborators had different expertise that fitted well with the research objectives. Mentorships were both provided by the team members of the project and stakeholders who have been working with safflower and the localities where the project was implemented.

Project implementation was delayed by COVID-19 pandemic lockdowns. However, for the MSc and PhD students to complete coursework and defend their research proposals blended learning (on-line lectures using Moodle with face-to-face practicals) was introduced. Farmer training was done via WhatsApp and video calling.

2.5 Seed Multiplication

During the first six months of the project, safflower germplasm was be bulked (multiplied) at the Botswana University of Agriculture and Natural Resources (BUAN), Content Farm and at two farmer groups Kweneng North Horticultural Co-operative (Kweneng district) and Saff Energy Initiative Mult-Purpose Co-Operative (Central district). Members of the two co-operatives were trained in safflower seed multiplication being a self-pollinated crop. After the initial seed multiplication, the two farmer co-operatives and individual farmers were identified to be safflower seed producers.

2.6 Farmer Training

Farmers in groups, individual farmers, and community-based organizations were trained in safflower agronomy, vegetable and herbal tea (petals and leaves) production, vegetables, animal feed making (cake, meal, seed, roughage, hay, silage), and cooking oil extraction. The stakeholders were also trained in modern packaging and packaging of safflower products, record keeping, entrepreneurship, and handling and marketing of safflower products. Training was done as on-farm demonstrations and lectures using appropriate facilities (tents, chief's centres, and auditoriums) and sometimes under trees shown in the figures below. Later Lead farmers started training other farmers at a fee as shown in the figures below due to the high demand of the safflower products and many farmers wanting to grow safflower. The demand for safflower training was escalated by changes in government policy. In the Botswana Government quest to enhance household food security by ensuring that micro-scale farmers can produce enough output to contribute significantly to household food consumption needs; promote commercial production of grain by improving access by crop producers to inputs, credit and other essential services; promote inclusivity in agricultural production by building rainfed agricultural production systems by facilitating financial access to all commercially-focused farmers; and improve the social capital base by promoting collective bargaining of rainfed producers, safflower was among the 13 crops included and supported by the new programme 'Temo-Letlotlo' which was implemented in April 2023 with the goal to promote production of cooking oil from safflower and sunflower and reduce imports of cooking oil. The government shall give subsidies to all farmers in the country to produce and process safflower, therefore this will increase the hectarage under safflower and improve food security and nutrition. This new programme (Temo-Letlotlo) was implemented in the 2024 planting season (January 2024 due to drought).

Figure 8a. On-farm farmer training in Metsimotlhabe Kweneng District in a tent

Figure 8b. Extension Officer (lady in red jersey) demonstrating to plant safflower along drip lines in Metsimotlhabe Kweneng District.

Figure 8c. Lead farmer training other farmers under a tree in Ramotswa South-East District, behind safflower farm ready for harvest, Photographer PI.

Figure 8d. Lead farmer showing to other farmers safflower oil he had extracted Ramotswa South-East district under a tree.

Figure 8e. Field Day in Molepolole showing farmers safflower plants (yellow) and products in Molepolole Kweneng district

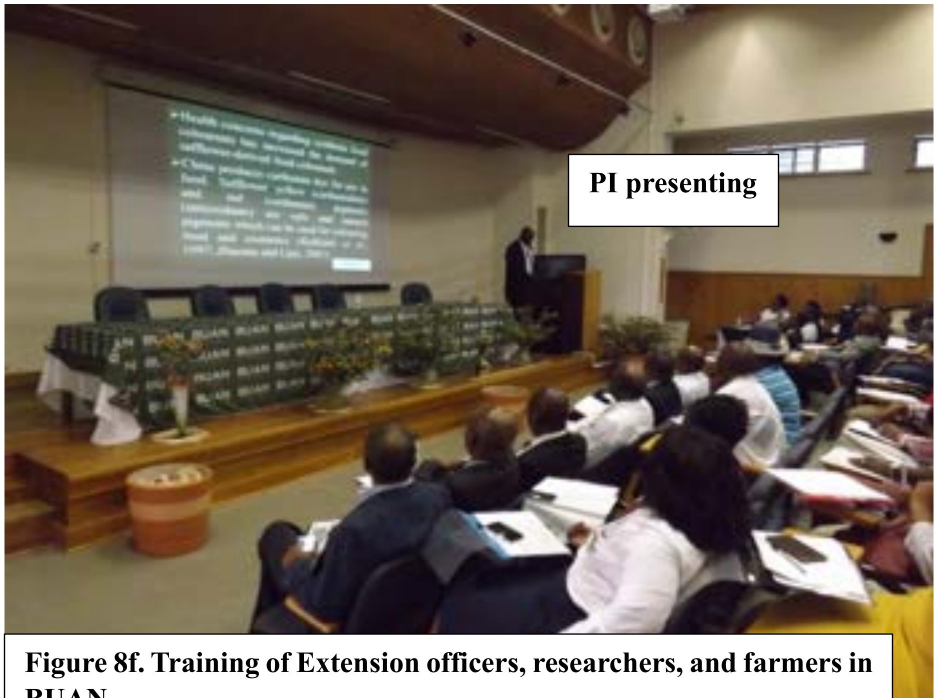


Figure 8f. Training of Extension officers, researchers, and farmers in BUAN.

Figure 8g. PI demonstrating to a farmer how to harvest safflower petals in Lethakeng Kweneng district.

Figures 8 h. Lead farmers advertsing safflower training at a fee in different parts of the country

Figure8i. Field demonstration of safflower oil extraction.

Figure 8j. Safflower seed oil extraction demonstration in BUAN.

2.7 Systematic Inclusion of TVET Institutions and Moeng College

Technical and vocational education training institutions (TVETs) help to create local jobs, contribute to economic structure transfer, and labour restructuring in rural areas, thus contributing to poverty reduction. In this CARP project, Kgatleng Brigades (Kgatleng district) agreed to collaborate with the research team. The goal of including TVET institution was to bring together the university (BUAN) and Kgatleng Brigades so that they may complement each other. TVETs are often closer to communities than universities. The Kgatleng Brigades were to design and develop a safflower planter with financial assistance from the safflower CARP. This done through the leadership of Mr. Matsapa (Lecturer Kgatleng Brigades) and 10 students being trained for metal work at the institution. The safflower CARP research team in collaboration with BUAN supplied all the materials needed for the development of the safflower planter as shown in Figures 9-14 below.

The PI and other BUAN staff members of staff trained form four and five students plus agriculture teachers of Moeng College on safflower production and its benefits during the science week 5-9th August 2024. Safflower planting was demonstrated and the agriculture students planted 20 rows each 40 m long under drip irrigation on 9th August 2024.

Figure 9. Safflower CARP research team with Kgatleng Brigades staff (two ladies right and two gentlemen one kneeling and one directly behind the kneeling gentleman).

Figure 10. Delivery of steel bars and plates to Kgatleng Brigades.

Figure 11. After offloading some of the metal bars in the Kgatleng Brigades metal workshop.

Figure 12. The PI, Deputy-Principal (white jacket) and Lecturer in the institution inside Kgatleng Brigades workshop.

Figure 13. PI, CARP Researcher (right), Deputy-Principal and Lecturer in Kgatleng Brigades workshop on the floor metal plates delivered by research team.

Figure 14. Prototype of safflower planter with chamber for fertilizer application.

2.8 Data Collection Methods

In line with RUFORUM's focus on capacity building, implementation of the project was centred on four PhD (two sponsored by the project) and six MSc students (four sponsored by the project). Gender balance was taken into consideration in recruitment of students (8 females and two males). The students (nine) were registered with the Crop and Soil Sciences Department, Botswana University of Agriculture and Natural Resources, and one PhD student (developed safflower biodiesel) was registered in the Department of Engineering, University of Botswana. The experiments were carried out at Central, Kweneng, Kgatleng, North-East, Southern, and South-East districts on-farmer's fields.

2.9 PhD Students

Introduction of cultivation of a climate smart crop such as safflower in Botswana was ideal because the country is water deficient and some of the soils are saline with extreme temperature variation (-6.6-43°C) depending on season and district. Safflower cultivation can contribute to diversification, commercialisation of production and bridge the gap of edible oil shortage and base for formulation of animal feeds in the country. However, introducing a new crop to a regional cropping system requires information on its performance under local agronomic and environmental conditions (Mazumdar et al., 2007; Oad et al., 2002; Ulsu et al., 1998). Proper plant population densities with appropriate row and plant distance adjustment are the most essential factors for increased safflower grain yields (Oad et al., 2002; Nabavicalat et al., 2004; Mazumdar et al., 2007). Plant density among safflower cultivars has a significant influence on soil moisture availability, radiation distribution, photosynthetic activity (Mohamadzadeh, 2011) and mineral absorption from the soil to the plant (Ahmadian et al., 2011).

Information on the proper plant density for optimum production of safflower was necessary in designing a management system that allowed maximum expression of genetic potential required for Botswana. Plant density plays an important economic role, as seed price is an important part of the total production cost (Emongor et al*.,* 2015). There is significant variation in safflower plant density recommended in literature, depending in climatic conditions, cultural practices and countries (Sampaio et al., 2017; Emongor et al., 2015; Elfadl et al., 2009; Oad et al*.,* 2002; Dajue & Mundel, 1996; Gonzalez et al., 1994). Information on the response of safflower to plant density and genotype pertaining growth, phenology, yield, yield components, seed oil content and composition in Africa and Southern Africa Development Community (SADC) was not available, except the work of Emongor et al. (2015). Therefore, this CARP project intends to generate information to fill this existing knowledge gap. Therefore, the first PhD student evaluated the effects of plant density and genotypes on yield and yield components, oil content and yield, and oil composition of safflower. The overall objective of this study was to evaluate the adaptability of safflower germplasm and plant density in Botswana using agromorphological and biochemical traits in seed with the aim of mitigating the effects of drought and climate change, improve food security, increase income and social welfare of farmers in Botswana, and to reduce reliance on food importation. The specific objectives were to evaluate influence of: 1) plant density and genotype on yield and yield components of safflower in Botswana; 2) plant density and genotype on seed oil content, yield and composition of safflower in Botswana; and 3) growing season on yield and yield components, seed oil content, yield and composition of safflower in Botswana. The treatments were five safflower genotypes (Kiama composite (local), Sina-PI 537 598, Gila-PI537692, PI537636, and PI527710) and six plant densities (62,500, 83,333, 100,000, 125,000, 166,666 and 200,000 plants/ha). Four field experiments were carried out on-farm in Sebele South-East district. The dependent variables determined were phenology of safflower, vegetative growth variables (leaf area index, leaf area duration, crop growth rate, net assimilation rate, plant height, number of primary branches per plant, and leaf chlorophyll content), yield components (capitula number per plant, capitula size, seed (achene) number per capitulum, 1000-seed weight, and biological yield), seed yield, oil content, oil yield, and oil composition. The fatty acid composition was determined according to AOAC (1996) and AOACS (2003). The oil sample extracted was used to prepare fatty acid methyl esters (FAME) through acid-catalysed trans-esterification as described by AOAC (1996). The FAME of the oils in dichloromethane were analysed in a Gas Chromatography (GC) system (Agilent 7890A) with automated sampler (G4513A) coupled to Mass Spectophotometry (Agillent 5957C) with triple axis detector.

Even though safflower is known to grow in diverse environments, evaluation of its performance in Botswana climatic condition is still at an infancy stage. Very few genotypes have been evaluated in varying locations of Botswana. In addition to evaluating the productivity of genotypes across different locations, it is also important to know the performance of each genotype across different planting seasons (summer and winter). This is due to the fact that summer crop genotypes from temperate regions sown as a winter-crop in sub-tropical and tropical regions, tend to have a lengthy rosette stage, which greatly delays maturity (Dajue & Mundel, 1996). Thus, as part of introducing safflower in Botswana, it was of major importance to know the interaction of genotype and environment on the productivity of safflower. Information on how safflower genotypes interact with the environments will be useful in selection of the most stable and adaptable genotypes. This is because farmers in developing countries, use no or limited inputs and grow safflower under harsh and unpredictable environments, and they need more stable varieties (Mohammadi et al., 2008). Moreover, planting safflower on the farmers' fields will help farmers appreciate the crop and thereby, accelerating its adoption in Botswana. Therefore, the second PhD student did on-farm trials to assess the influence of season, location, and safflower genotypes and their interactions on the growth, phenological development, oil content, yield, and yield components of safflower. The objective of the study was to evaluate different safflower genotypes across different sites in the Southern region of Botswana as a way of selecting the most stable and adaptable genotypes for the region and to evaluate the drought tolerance mechanisms of each genotype. The specific objectives were to: 1) evaluate the influence of environment, genotype and their interaction on the growth, phenological development, and oil content in selection of the most adaptable and stable genotypes across all the study sites; 2) assess the relationship between oleosin gene expression, oil body size and the oil content of safflower genotypes; and 3) determine the growth and the activities of drought related antioxidants (proline and ascorbate peroxidase) among safflower genotypes under drought stress. The study was conducted in summer and winter at three sites (Sebele, Ramonaka, and Molepolole). The genotypes used in the research wereTurkey, Sina, PI537636, Kenya9819, and Gila. The relationship between oleosin genes and oil bodies in regulating the oil content of safflower seeds was achieved by isolation and quantifying the oleosin genes and oil bodies from the seeds of five (Gila, Turkey, Sina, PI537636, and Kenya9819) safflower genotypes using qPCR and fluorescence microscope, respectively and assessed them against the seed oil content. Growth, development, and yield of safflower genotypes in response to seasonal variations was also determined. The dependent variables analysed were plant phenology, vegetative variables, yield components, seed yield, oil content, and oil yield. In a study to evaluate the response of safflower genotypes to drought stress under greenhouse and field conditions, the dependent variables that were determined were relative water content (RWC), vegetative variables (plant height and chlorophyll content), ascorbate peroxidase (APX), and proline content

Chilling injury is one of the major abiotic stresses which influences the production and quality of the most economically important crops of tropical and subtropical origin. Although safflower is cold tolerant, the level of tolerance significantly differs with phenological stages. This problem was observed by the research team and farmers in the colder districts of Botswana where in July and early August in some day's night temperatures drop to -6.4°C or below. These low temperatures destroyed safflower in Southern, Kgatleng, and Kweneng districts. Chilling injury (CI) posed a major threat to safflower growers in Botswana during winter. Therefore, the research team wanted to know the phenological stage, temperature in which CI occurs in safflower, duration exposure to CI, and physiological, biochemical, and molecular factors involved in CI of safflower. Therefore, the third did on-farm trial in Sebele South-East district evaluated the influence of low temperature and duration of exposure on chilling injury and severity; photosynthetic variables as indicators of chilling injury, biochemical and molecular changes caused by chilling injury; physiological response and cold responsive genes expressed at critical growth stages of safflower to provide novel insight about the different responses of safflower growth stages to cold stress. Expression of cold stress genes was done by extraction of RNA and cDNA synthesis, followed by selection of genes of interest and design of primers, and lastly quantification of safflower genes.

The fourth PhD student evaluated the influence of plant growth regulators (PGRs) on safflower oil yield and fuel properties of derived biodiesel. Four PGRs kinetin, benzyaladenine, maleic hydrazine, and 2, 3, 5 triiodobenzoic acid were used in the study. The extracted oil was converted to biodiesel through the process of transesterification, and derived biodiesel characterized to establish chemical composition using MS-GC instrumentation. Fuel quality analyses of biodiesel was performed in terms of free fatty acids, flash point, cloud and pour points, kinematic viscosity, cetane number, esters, density, iodine value, sulphur content, carbon residue, moisture content, and energy content using ASTMD 664, ASTM D93, ASTM D2500, ASTM D97, ASTM D445, ASTM D6890, EN14103, ASTM D 1298, EN 1411, ASTM D4530, ASTM D2709 EN 12662 and ASTM D 240 methods, respectively. The study was undertaken at Sebele South-East district of Botswana.

Table 2. PhD students trained under safflower CARP	
PhD Student	Contact
 Dineo Kereilwe	Contact: +267 74816972 Email: dineophuduhudu@yahoo.com Nationality: Motswana Worked on physiology of chilling injury in safflower.
 Dr. Moatshe Onkgokolotse	Cell: +26774195359 Email: moatsheonkgolotse@gmail.com Nationality: Motswana Evaluate the adaptability of safflower germplasm and plant density in Botswana using agromorphological and biochemical traits.
 Mosupiemang Marang	Cell: +26774623062 Email: marangmosupiemang@yahoo.com Nationality: Motswana Evaluated different safflower genotypes across different sites in the Southern region of Botswana as a way of selecting the most stable and adaptable genotypes for the region and drought tolerance mechanisms of safflower.
 Charles Mazereku	Cell: +2677934840 Email: cmazereku@yahoo.com Or charmazereku@gmail.com Nationality: Motswana Developed safflower biodiesel as he worked on the influence of plant growth regulators on safflower growth, development, seed and oi yields, and oil content.

2.10 MSc Students

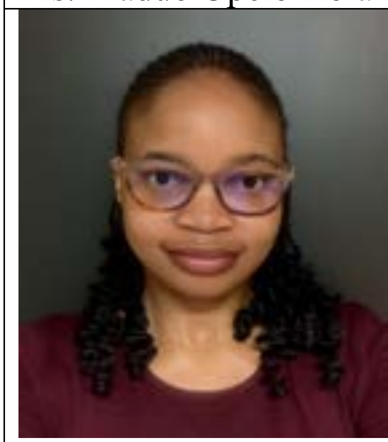
Various factors such as habitat loss, pollution, environmental changes, introduction of new crops to new habitats and chemical manipulation can change the biodiversity level of different insects. Insects have a variety of functions ranging from destructive to beneficial aspects. Safflower crop is reported to be attacked by 101 pests at different phenological stages of crop development worldwide (Singh et al., 2013). However, these insect pests and their natural enemies have not been evaluated in Botswana. Therefore, the first MSc student undertook on-farm trials in Molepolole (Kweneng district) in summer and winter. The student determined the abundance and diversity of arthropods on different safflower genotypes under field conditions. The specific objectives were to assess: 1) diversity and abundance of arthropods on safflower genotypes, and phenological stages; 2) and identify the predominant and major arthropods and pests of safflower; 3) and identify parts of safflower plant attacked by arthropods; 4) establish the relationship between safflower arthropods and weather variables, and safflower pests and safflower seed yield; 5) to establish the relationship between safflower pests and safflower seed yield. Insects survey was carried out in two seasons; summer and winter, on five different safflower genotypes; Gila, PI-537636, Kenya-9819, Turkey and Sina. Collection of data and specimens was done once a week and identification was carried out at the Botswana University of Agriculture and Natural Resources, Entomology Laboratory. Data collected were analysed using descriptive statistics (frequencies and percentages). Variation in insects' abundance between genotypes and plant growth stages was determined by analysis of variance. Diversity indices were computed using Shannon diversity index, Sorensen's index and Margalef's richness index. Correlation analysis was used to establish relationships between population of insects, weather parameters and yield.

In general, plants require mineral elements provided by the soil for growth and development. However, Botswana's soils are poor and deficient in nitrogen (N) and phosphorus (P), thus limiting crop production (Botswana Agriculture Sector Policy Brief, 2012; Emongor & Mabe, 2012; Malikongwa, 2015; Emongor et al., 2017b). The amount of nutrients in the soil must be maintained at a sufficient level throughout the crop's growth stages. Therefore, fertilizer application is a critical measure for correcting nutrient deficits by replacing components eliminated from harvested products (Abbadi, 2007). Kubsad et al. (2001) demonstrated that safflower requires an adequate supply of nutrients even when moisture is scarce. While Golzarfar et al. (2012) identified N and P as the two most critical essential elements for safflower growth and development. Nitrogen and P nutrition of safflower in Botswana or within the Southern Development Agency Cooperation (SADC) countries has not been done. Therefore, the second MSc student undertook on-farm trials in Molepolole (Kweneng district) in summer and winter. The student determined N and P fertilizer requirements of safflower to maximize growth, seed yield, and oil content under field conditions. The specific objective of the study was to evaluate the influence of N and P fertilizer application on growth, seed yield, and oil content of safflower. The treatments were N (main plots) applied as calcium ammonium nitrate (28 % N), while P (sub-plots) was applied as single super phosphate (8.3 % P). Prior to planting, the soil was sampled at a depth of 30 cm to determine the physicochemical properties and total N and P. Nitrogen was applied at 0, 40, 80, and 120 kg N/ha in two splits. The first split was applied two weeks after emergence and the second split was applied at the bolling stage of safflower. Phosphorus was applied at 0, 25, 50, and 75 kg/ha P_2O_5 two weeks after emergence. At the end of each trial, total N and P were determined in the experimental plots. The dependent variables determined were height to first branching, plant height, stem diameter, leaf area, leaf chlorophyll content, number of primary branches per plant, number of capitula per plant, capitula diameter, seed number per capitulum, 1000-seed weight, plant biomass, seed yield, oil content (%), oil yield and leaf N and P, nitrogen use efficiency (NUE), nitrogen uptake efficiency (NUpE), phosphorus use efficiency (PUE), and phosphorus uptake efficiency (PUpE).

Safflower research carried out in Botswana and worldwide has been inclined to adaptability, population, plant nutrition, and use of safflower as animal feed and medicinal purposes rather than petal production. Thus, this study was carried out to bridge the knowledge gap on the optimal time to harvest safflower petals at their peak for maximum petal yield, seed yield, and dye content of safflower. Information regarding the ideal time to collect safflower petals will facilitate production of high-quality petals to be used in various industrial purposes such as pharmaceutical, food, cosmetic, and textile. Therefore, the third MSc student undertook on-farm trials in Sebele (South-East district) in summer and winter. The student determined the influence of harvest time and genotype on seed yield, petal yield and carthamidin and carthamin contents, and mineral nutritional content in safflower (*Carthamus tinctorius* L.) petals. The specific objective of this study was to evaluate the effects of petal harvest time and genotype on petal yield, seed yield, carthamidin and carthamin contents, and mineral nutritional contents of safflower petals. The experimental design was a split-plot in randomized complete blocks with three replications. The treatments were three safflower genotypes, and four petal harvest times assessed evaluated in both growth seasons, summer, and winter. The genotypes were Sina (spiny, yellow flowers), Kenya-9819 (spiny, yellow flowers), and Turkey (spineless, red/orange flowers) randomly assigned to the main plots. The four petal harvest times included the onset of flowering, full bloom, post-pollination, and end of flowering (petals have wilted control) randomly assigned to sub-plots. The dependent variables determined were days to emergence, days to end of flowering, days to physiological maturation, height of the plant, numbers of main branches, capitulum diameter, the number of capitula per plant, total number of seeds per capitulum, thousand seed weight, the yield of seeds, petal yield, carthamin, and carthamidin contents, and proximate analysis of petals (moisture content, crude fibre, crude protein, fat content, ash content, carbohydrates, and minerals) (AOAC, 1996).

Nutritional management is one of the most crucial operations for high yields in crop production. However, crop nutritional management can affect the response of pests in terms of abundance, diversity, developmental patterns, and their natural enemies ((Magdoff et al., 2000). Therefore, these nutrients do not only have potential in improving crop production, but they can also make the crop either susceptible or resistant to pests (Bala et al., 2018). Fertilizer application is important in correcting nutrient deficiencies since most soils in Botswana are saline and deficient in N and P (Emongor & Mabe, 2012). Currently there is no research work done on the response of safflower insects to N and P fertilizer application in Botswana. Therefore, the fourth MSc student undertook on-farm trials in Sebele (South-East district) in summer and winter. The objective of the study was to evaluate the response of safflower insects to nitrogen and phosphorus fertiliser application rates with the goal to improve food security in Botswana. The specific objective was to determine the effect of N and P and their interactions on the occurrence, abundance, and diversity of safflower insects. The experimental design used was a 5x5 factorial in randomized complete blocks with three replications. The treatments were N applied at 0, 40, 80, 120, 160 kg/ha (applied as calcium nitrate 28%N) and P at 0, 20, 40, 60, 80 kg/ha (applied as single super phosphate 8.3%P). Phosphorus was banded two weeks after emergence. Nitrogen was applied in two splits. The first split was applied two weeks after emergence and the second split was applied at the onset of flowering. Insects survey was carried out in two seasons: summer and winter, on one safflower genotype Sina. Collection of data and specimens was done once a week and identification was carried out at the Botswana University of Agriculture and Natural Resources, Entomology Laboratory. Data collected were analysed using descriptive statistics (frequencies and percentages). Variation in insects' abundance between nitrogen and phosphorus application rates and their interactions at different phenological stages of safflower was determined by analysis of variance. Diversity indices were computed using Shannon diversity index, Sorensen's index and Margalef's richness index. Correlation analysis was used to establish relationships between population of insects, weather parameters and yield.

The above research was done on-farm (farmer's selected farms). The farmers were involved in the management of the crop in collaboration with the researchers because before the start of research the farmers were trained in safflower agronomy. The farmers were involved in land preparation, planting, weeding, irrigation where necessary, fertilizer application, vegetable, petal and seed harvesting, threshing of harvested plants, and packaging of petals.

Table 3. MSc students trained under safflower CARP	
MSc Student	Contact
 Ms. Maduo Opelo Kolanyane	Cell: +26776256851 Email: maduoopelokolanyane@gmail.com Nationality: Mostwana Determined N and P fertilizer requirements of safflower to maximize growth, seed yield, and oil content.
 Ms. Bonolo Setshogela	Cell: +26776499976 Email: bsetshogela91@gmail.com Nationality: Motswana Determined the influence of harvest time and genotype on seed yield, petal yield and carthamidin and carthamin contents, and mineral nutritional content in safflower.
 Mr. Pako Monyame	Cell: +26777415886 Email: pmonyame@hotmail.com Nationality: Motswana Evaluated the response of safflower insects to nitrogen and phosphorus fertiliser application rates.
 Ms. Basiame Keheng	Cell: +26771225317 Email: kbasiame@gmail.com Nationality: Motswana Determined the abundance and diversity of arthropods on different safflower genotypes under field conditions.

2.11 Safflower Product Development

The Community Action Research Projects (CARPs) are a unique 'scaling laboratories' approach to co-creating solutions that gives a new orientation to universities: both in their purpose and in how they engage with society (Egeru et al., 2024). The participatory, multi-disciplinary, multi-sector orientation of the CARP platforms widens the field of engagement, further enriching practical and experiential learning. These combined approaches provided more relevant training to students and farmers because were engaged in real life situations.

The safflower CARP project started by having dialogues with communities and relevant stakeholders to establish research problems for the researchers and farmers to address together. Through dialogue, the research team and community members developed mutual understanding of the opportunities and challenges of collaboration, and from this research proposals were developed. By addressing the entry points first, the researcher team and farmers were able to remove critical barriers to enable farmers to progress. Some of the barriers included the lack of safflower seeds and value chains, and water scarcity since Botswana is a water deficit country. The participatory, multi-disciplinary, multi-sector orientation of the safflower CARP allowed the research team and farmers in the safflower CARP to develop various safflower products that are beneficial to the community and humanity at large. The safflower value chain is long because of the potential products that can be developed in the food, pharmaceuticals, textile, paint, energy (biodiesel), and cosmetic industries.

2.11.1 Safflower Cooking Oil

Safflower cooking oil is considered healthier than olive and canola oils (Bergman, 1997, Corleto *et al*., 1997; Moatshe et al., 2020; Emongor & Emongor, 2024) and sunflower oil (Dajue and Mündel, 1996) due to its lower percentage of saturated fatty acids. Safflower oil contains over 90% monounsaturated and polyunsaturated fatty acids with a very content of saturated fatty acids (Emongor & 2024). The PI, Co-PI, and Participating Researcher with relevant stakeholders trained farmers in safflower oil extraction from seeds. The farmers were encouraged to form co-operatives to take advantage of economies of scale (more production by operating on a larger scale) to lower costs for everyone. Figure 15 shows safflower oil extracting machine bought by safflower CARP.

Figure 15. Safflower extraction machine

Figure 16. Safflower seeds, herbal tea (petals), safflower jelly, and tissue oil.

Figure 17. Safflower jelly various sizes and cooking oil.

Figure 18. Shows safflower cooking oil, jelly and seed.

Figure 19. Safflower products displayed for sale in the Gaborone National Agricultural Show 19th-24th August 2024. **Note: Farmers and other stakeholders have developed safflower jelly, lotion, lip balm, tissue oil, and soap from safflower oil (Figure 16-19).**

2.11.2 Safflower petal (flower) and green (leaves) tea

The safflower CARP research team trained farmers how to process and package safflower petal and green tea because of their human health benefits (Li & Yuanzhou, 1993; Sawant et al., 2000; Singh, 2005; Emongor, 2010; Emongor & Oagile, 2017).

Figure 20. Safflower petal (flowers) tea; improves blood circulation, lowers blood pressure and cholesterol, regulates blood sugar, prevents coronary heart ailment and deep vein thrombosis, improves male and female fertility, and helps in melanin formation (may help vitiligo cases).

Safflower flowers are used to make herbal tea because they have purgative, analgesic, and antipyretic characteristics, and can be used to treat patients with poisoning (Asgarpanah & Kazemivash, 2013). Safflower flower tea decoctions and concoctions are used in the treatment of menstrual cramps, post-partum hemorrhage, whooping cough, chronic bronchitis, rheumatism, and sciatica (Zhou, 1986; More et al., 2005; Luo et al., 2019; Adamska & Biernacka, 2021) and cardiovascular, cerebrovascular, and gynecological complications (More et al., 2005; Han et al., 2016; Ao et al., 2018; Hu et al., 2020; Chen et al., 2020; Mani *et al*., 2020) . Safflower petal extracts have been shown to contain anticoagulant, vasodilating, antihypertensive, antioxidative, neuroprotective, and immunoprotective (Bie et al., 2010; Liu et al., 2018; Tan et al., 2020), and anticancer agents (Ma et al., 2019; Qu *et al*., 2019), with promotive impacts on melanin synthesis (Yin et al.,2015; Adamska & Biernacka, 2021).

Severe sepsis and septic shock are the leading causes of high mortality (Angus et al., 2001; Russel et al., 2008; Perner & Haase, 2012; Asfar et al., 2014; Li et al., 2016). Safflower yellow A has been demonstrated to significantly reduce mortality and increase survival in severe sepsis and septic shock patients (Li et al., 2016). Safflower yellow A has been reported to improve the hemodynamic index of patients with severe sepsis and septic shock by increasing blood pressure and decreasing heart rate, thus improving the tissue and organ perfusion indices (Li et al., 2016). The decreased heart rate conferred advantages such as lengthening coronary diastolic perfusion time, improving coronary perfusion, and alleviating myocardial ischemia and hypoxia (Li et al., 2016). The phytochemistry of safflower petals indicates several active compounds, including flavonoids, hydroxysafflor yellow A, phenylethanoid glycosides, coumarins, fatty acids, and steroids, in various plant parts (Zhou et al., 2009; Li et al., 2016; Zhang et al., 2017).

The main components of safflower petals are carthamidin (yellow) and carthamin (red) (Tang & Eisenbrand, 1992; Asparpanah & Kazemivash, 2013; Zhang et al., 2017; Setshogela & Emongor, 2021; Setshogela, 2024) used as natural food, beverages, pharmaceuticals, cosmetics, textiles, and carpets colourants (Oelke et al., 1992; Watanabe & Terabe, 2000; Zohary & Hopf, 2000; Ekin, 2005; Shin et al., 2008; Badiger et al., 2009; Garcia, 2009; Emongor, 2010; Coronado, 2010; Setshogela & Emongor, 2021; Setshogela, 2024). The demand of safflower petal extracts as a source of natural food colourant has increased due to a ban on the use of synthetic colourants in foods in European countries and elsewhere and health-conscious consumers moving away from synthetic food colourants and demanding naturally derived food colourants (Singh & Nimbkar, 2006; Emongor, 2010; Katz & Williams, 2011; Jadhav & Joshi, 2015; Bagley, 2017; Vogel, 2018; Setshogela & Emongor, 2021; Setshogela, 2024). Dried safflower leaves are used to make safflower green tea, and its benefits are like petal tea. Safflower leaves contain chemicals that helps prevent blood clots, widen blood vessels, lower blood pressure, and stimulate the heart (Li et al., 2016).

Figure 21. Farmers selling ready to drink safflower petal tea and safflower green tea.

Figure 22. Safflower green tea.

2.11.3 Safflower green vegetables

Safflower leaves are a good source of minerals, vitamins, fibre, and antioxidants. Safflower leaves are eaten as vegetables (Sigh *et al*., 2017; Phuduhudu, 2017; Kereilwe et al., 2020; Moatshe et al., 2020c; Emongor & Emongor, 2023). Safflower vegetables are rich in carotene (1.48-14.89 mg/100g), protein (21.0–29.7%), fat (1.1–2.8%), riboflavin, vitamins A and C (5.92–19.0 mg/100 g), iron (3.42–55.1 mg/100 g), phosphorus (175–250 mg/100 g), calcium (185–708 mg/100 g), magnesium (142–220 mg/100 g), potassium (1510–1780 mg/100 g), sodium (469–581 mg/100 g), antioxidants, and fiber (Singh & Nimbkar, 2006; Phuduhudu, 2017; Moatshe et al., 2020c; Emongor & Emongor, 2023).

Figure 23. Safflower grown for vegetables

Figure 24. Rakops women preparing safflower vegetables for the market

Figure 25. Safflower packaged with nutrition content in one of supermarkets in Botswana.

Figure 26. Safflower green vegetables in the supermarket.

2.11.4 Livestock feed

Safflower can be grown in regions with relatively low temperatures (Koutroubas & Papadoska, 2005; Emongor et al., 2015), saline soils (Kaya et al., 2003), and water deficit (Leshem et al., 2000; Bassil & Kaffka, 2002; Yau, 2007; Bar-Tal et al., 2008; Emongor, 2010; Emongor & Oagile, 2017) where most fodder crops cannot grow. Safflower can be used as fodder of high nutritive value when harvested at the onset of flowering (Standford *et al*., 2001; Berglund *et al.,* 2007; Peiretti, 2017). Safflower is a cheap source of natural polyunsatured fatty acids (PUFAs) and monounsaturated fatty acids (MUFAs) for livestock (Phuduhudu, 2017; Phuduhudu et al., 2018; Moatshe, 2019; Moatshe et al., 2020a). Safflower can be grazed directly or preserved as silage or hay (Weinberg et al., 2002; Corleto et al., 2005; Landau et al., 2005). Safflower seed, meal, and cake can be used as protein and energy supplements for animal nutrition (Chidoh, 2012, Phuduhudu, 2017; Phuduhudu et al., 2018; Peiretti, 2017; Kereilwe et al., 2020). Whole safflower seeds are good sources of fat for lactating dairy cows (Stegeman et al., 1992; Alizadeh et al., 2010). Safflower cake or meal is high in protein (40–55%) (Phuduhudu, 2017, Phuduhudu et al., 2018; Kereilwe et al., 2020) and thus can be used as a protein supplement for low protein forages in ruminant diets or poultry backgrounding diets (Yadav & Mathur, 2009; Ehsani et al., 2014).

Figure 27. Safflower seed, cake, and roughage are used as livestock feed.

The safflower CARP project developed livestock feed including safflower seed, cake after oil extraction, and roughage (green and dry) as shown in Figure 26 above. The green roughage is processed after the safflower has flowered but before the plants dry. The green roughage is more nutritious since it contains immature seeds good for lactating dairy animals, finishing beef animals, goods, sheep, and other ruminants.

Figure 28. Safflower plants in the elongation stage, suitable for grazing, and making silage or hay for livestock.

Figure 29. Farmer feeding bull with safflower

2.11.5 Cut flowers

The safflower advised farmers also to sell safflower cut flowers for income generation. Safflower cut flowers are harvested when petals are visible on most of the flowers, and flowers are one-quarter to one-half open, as buds do not open well after harvest; freshly cut flowers usually last up to 10 days (Dole & Wilkins, 2005; Emongor & Oagile, 2017). Currently farmers are selling each cut stem for 2 BWP (0.13US$) when grown in winter and each plant produce up to 20 stems. In the year 2000, 35.2 million flowering stems of safflower were supplied to Dutch cooperative flower auctions for total sales of €5.3 million, with safflower ranked 39th among all cut flowers of commercial significance (Uher, 2008; Emongor & Emongor, 2023). Figure 30-31 shows safflower cut flowers in Botswana.

Figure 30. Fresh safflower cut flowers

Figure 31. Dried safflower cut flowers

2. 12 MONITORING AND EVALUATION

This CARP project was managed by The Botswana University of Agriculture and Natural Resources (BUAN). The project was supervised by the Vice-Chancellor, Dean, Faculty of Agriculture, Dean of Research and Graduate Studies, and Head of Department Crop and Soil Sciences, BUAN. This task force overseed, guided and closely supervised the implementation of the project which led to the milestones achieved reported in this report. The monitoring and evaluation plus project backstopping was performed by RUFORUM which the research team was grateful. The effectiveness of the partnership between the researchers, the farmers (farmer associations) and TVET institution were demonstrated in the outputs or achievements reported in this report. Ex-post survey will be done twelve months after the life of the project to evaluate the impact of the project on farmer income levels, wellness, reduced import of cooking oil, animal feeds, and vegetables especially after the implementation of government policy Temo-Letlotlo program that supported safflower farmers.

CHAPTER 3

3.0 PROJECT OUTCOMES/ACHIEVEMENTS

3.1 Capacity Building.

3.1.1 Research

In line with RUFORUM's vision 2030 (vibrant, transformative universities catalysing sustainable, inclusive agricultural development to feed and create prosperity for Africa) and goal of capacity building in agricultural research four PhD (two sponsored by the project) and six MSc students (four sponsored by the project) have been trained. The student's academic and research progress is shown in Tables 2 and 3 below.

Table 4. Student academic and research progress as of August 2024.

PhD students			
Name of Student	Degree and Thesis Title	Supervisors	Remarks
Moatshe Onkgokolotse	PhD Crop Science (Horticulture). Genotype and plant density effects on growth, yield and oil composition of safflower (*Carthamus tinctorius* L.)	Prof. V. E. Emongor. Prof. S.O. Tshwenyane Dr. T. B. Balole	• 7 papers published in peer reviewed journals. • Graduated • Working as Scientific Officer Ministry of Agricultural Development and Food Security (MoA).
Marang Mosupiemang	PhD Crop Science (Horticulture). Safflower growth, development, yield and oil content as influenced by genotype and environment interaction under on-farm conditions.	Prof. V. E. Emongor Dr. G. Malambane Dr. R. Mapitse	• 3 papers published in peer reviewed journals. • 3 Conference papers. • Graduated • Working as a Research Assistant in BUAN.

Charles Mazereku	PhD Engineering and Technology. Effect of plant growth regulators on safflower oil yield and fuel properties of derived biodiesel.	Prof. Jerekias Gandure Prof. Clever Ketlogetswe.	• 2 papers published in peer reviewed journals. • Thesis under review by Supervisors. • Working as a Research Officer in the MoA
Mrs. Dineo Kereilwe	PhD Crop Science (Horticulture). Influence of temperature, duration of exposure and phenological stages on the incidence and severity of chilling injury on safflower.	Prof. V. Emongor Prof. U. Batlang Dr. G. Malambane	• 2 papers published in peer reviewed journals. • 2 papers published in conferences. • Completing research.
MSc Students			
Ms. Maduo Opelo Kolanyane	MSc Crop Science (Horticulture). The influence of nitrogen and phosphorus nutrition on growth and yield components of safflower (*Carthamus tinctorius* L.).	Prof. V. Emongor Dr. S. Moroke	• 1 Conference paper published. • Graduated • Working as Horticultural Extension Officer in the MoA.
Ms. Basiame Keheng	MSc Crop Science (Crop Protection). Abundance and diversity of safflower (Carthamus tinctorius L.) insects in Botswana.	Prof. B. Tiroesele Prof. V. E. Emongor	• 2 Conference papers published. • Graduated • Working as an Extension Officer MoA
Ms. Bonolo Setshogela	MSc Crop Science (Horticulture). Influence of harvest time and	Prof. V. E. Emongor Prof. B. Tiroesele	• 2 Conference papers published.

	genotype on seed yield, petal yield and carthamidin and carthamin contents, and mineral nutritional content in safflower (*Carthamus tinctorius* L.).		• Graduated • Working as Horticultural Extension Officer in the MoA.
Mr. Pako Monyame	MSc Crop Science (Crop Protection). Response of safflower insects to nitrogen and phosphorus fertiliser application rates.	Prof. B. Tiroesele Prof. V. E. Emongor	• 1 Conference paper published. • Graduated • Working as an Extension Officer in the MoA.

Table 5. Publications generated from the project
Book Chapters
1. Emongor, V. E., Tiroesele, B.,and Moatshe, O. M. (2023). Enhancing safflower Production and Product Development for Food Security and Improving Incomes of Small-scale Farmers in Botswana. In Egeru, A., Lindow, M. & Leresche, K. M. (Eds.), University Engagement with Farming Communities in Africa, Community Action Research Platforms, Routledge, Taylor & Francis Group. ISBN 987-1-032-48118-0. https://doi.org/10.4324/9781003387497. **2.** Emongor, V. E. and Emongor, R. E. (2023). Safflower (Carthamus tinctorius L.), pp. 683-731. In:Farooq, M and Siddique, H. M.K. (Editors), Negelected and Underutilized Crops: Smart Future Food, Academic Press, An Imprint of Elsevier, London, United Kingdom. https://www.elsevier.com/books/neglected-and-underutilized-crops/farooq/978-0-323-90537-4. ISBN: 978-0-323-90537-4.
Peer Reviewed Journal Papers
1. Mosupiemang, M., Emongor, V. E., Malambane, G., and Mapitse, R. (2023). Growth, development, and yield of safflower genotypes in response to environmental variations. Journal of Phytology, 15: 145-154. https//updatepublishing.com/journal/index.php/jp. Doi:10.25081/jp.2023.v15.8255. 2. Kereilwe, D., Emongor, V. E., and Malambane, G. (2023). Temperature and Duration of Exposure on Chilling Injury of Safflower. European Journal of Agriculture and Food Sciences. DOI: 10.24018/ejfood.2023.5.2.660. www.ejfood.org. 3. Mosupiemang, M., Malambane, G., Mathapa, B. G., and Emongor, V. E. (2022). Olesin expression patterns and size of oil bodies as a factor in determining oil content in

safflower (Carthamus tinctorius L.) genotypes. European Journal of Agriculture and Food Sciences, 4(5): 54-60. DOI: http://dx.doi.org/10.24018/ejfood.2022.4.5.570.

4. Mosupiemang, M., Emongor, V. E., and Malambane, G. (2022). A review of drought tolerance in safflower. International Journal of Plant & Soil Science,34(10): 140-149. DOI: 10.9734/IJPSS/2022/v34i1030930.
5. Moatshe, O. G., Emongor, V. E., and Mashiqa, P. K. (2020). Genotype effect on proximate analysis of safflower as green leafy vegetable. Journal of Agricultural Science 12(11): 1-8. Doi:10.5539/; URL: https://doi.org/10.5539.
6. Moatshe, O. G., Emongor, V. E., Balole, T. V. and Tshwenyane, S. O. (2020). Genotype and plant density effects on oil content and fatty acid composition of safflower. African Crop Science Journal 28: 83-101. DOI: https://dx\.doi.org/10.4314/acjs.v28il.7S.
7. Kereilwe, D., Emongor, V. E., Oagile, O. and Phole, O. (2020). Nutritional value of safflower whole seed as animal feed in semi-arid southern African conditions. African Crop Science Journal 28: 103-115. DOI: https://dx.doi.org/10.4314/acsj.v28il.8S.
8. Moatshe, O. G., Emongor, V. E., Balole, T. V. and Tshwenyane, S. O. (2020). Safflower genotype by plant density on yield and phenological characteristics. African Crop Science Journal 28: 145-163. DOI: https://dx.doi.org/10.4314/acsj.v28il.11S.
9. Moatshe, O. G., Emongor, V. E., and Mashiqa, P. K. (2020). Genotype effect on proximate analysis of safflower as green leafy vegetable. Journal of Agricultural Science 12(11): 1-8. Doi:10.5539/; URL: https://doi.org/10.5539.
10. Moatshe, G. O. and Emongor, V. E. (2019). Genotype, planting density and seasonal effects on phenological stages of Safflower (*Carthamus tinctorius* L.) in Sebele, Botswana. International Journal of Science and Research 8(12): 1201-1210. DOI:10.21275/ART20203114. ISSN:2319-7064.

Conference Papers

1. Emongor, V. E., Mosupiemng, M., Malambane, G., and Batlang, U. (2024). Mitigating and adapting to the Effects of climate change using safflower in the arid and semi-arid lands. Paper Presented at the 2nd RUFORUM Triennial Conference 12-16th August 2024 Windhoek, Namibia.
2. Kereilwe, D., Emongor, V. E., Malambane, G., and Batlang, U. (2024). Photosynthetic parameters as stress indicators in safflower. Paper Presented at the 2nd RUFORUM Triennial Conference 12-16th August 2024 Windhoek, Namibia.
3. Emongor, V. E., Tiroesele, B., and Moatshe, O. G. (2022). Enhancing safflower production and product development for food security and improving incomes of small-scale farmers in Botswana. Papers Presented in the RUFORUM AGM Scientific Conference 12-16th December 2022 Harare, Zimbabwe.
4. Basiame, K., Tiroesele, B., and Emongor, V. E. (2022). Abundance and diversity of safflower insect pests in Botswana. Paper Presented in the RUFORUM AGM Scientific Conference 12-16th December 2022 Harare, Zimbabwe.
5. Emongor, V. E., Tiroesele, B., and Moatshe, O. G. (2022). Enhancing safflower production and product development for food security and improving incomes of small-

scale farmers in Botswana. Paper Presented in the RUFORUM AGM Scientific Conference 12-16th December 2022 Harare, Zimbabwe.

6. Kereilwe, D., Emongor, V. E., Batlang, U., and Malambane, G. (2022). Temperature and duration of exposure on chilling injury of safflower. Papers Presented in the RUFORUM AGM Scientific Conference 12-16th December 2022 Harare, Zimbabwe.
7. Kolanyane, M.O., Moroke, T. S., Tiroesele, B., and Emongor, V. E. (2022). Influence of nitrogen and phosphorus on seed yield and oil content of safflower. Paper Presented in the RUFORUM AGM Scientific Conference 12-16th December 2022 Harare, Zimbabwe.
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PhD Theses

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2. Moatshe, O. G. (2019). Genotype and plant density effects on growth, yield, and oil composition of safflower *(Carthamus tinctorius* L.*)*. PhD Thesis, Botswana University of Agriculture and Natural Resources, Faculty of Agriculture, Crop and Soil Sciences Department.

MSc Theses

1. Monyame, P. (2024). Response of safflower insects to nitrogen and phosphorus fertiliser application rates. MSc Thesis, Faculty of Agriculture, Department of Crop and Soil Sciences, Botswana University of Agriculture and Natural Resources.
2. Setshogela, B. P. (2024). Influence of harvest time and genotype on seed yield, petal yield, carthamidin and carthamin contents, mineral nutritional content of safflower (*Carthamus tinctorius* L.). MSc. Thesis, Faculty of Agriculture, Department of Crop and Soil Sciences, Botswana University of Agriculture and Natural Resources. https://researchhub.buan.ac.bw/handle/13049/734.
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Extension Brochure

1. Emongor, V. E. and Tiroesele, B. (2024). Grow safflower the climate smart crop for cash and food in Botswana. RUFORUM Depository.
2. Emongor, V. E., Tiroesele, B., and Moatshe, O. G. (2022). Why grow safflower as a cash crop in Botswana. RUFORUM Depository.

Videos
1. Botswana Television (Btv). 2022. 'Documentary on Safflower'. Video. https://fb.watch/ikDVobLpGD/.
2. Ministry of Agriculture. 2022. Documentary on safflower. Video. https://www.facebook.com/share/p/19RGgfjPXB/.
3. Safflower Documentary video. https://www.facebook.com/share/p/1D7RrCVd8S/.

In summary 2 PhD theses, 4 MSc theses, 2 book chapters, 10 papers in peer reviewed journals with impact factors, 17 conference papers, 3 videos, and 2 extension brochures to date have been published through the research generated under this CARP project.

3.1.1.1 Summary of research findings

The project research findings confirmed that the optimum plant density that maximizes seed and oil yield, oil content, and fatty acid composition under ASAL conditions of Botswana to be 100,000 plants/ha at a spacing of 50 cm × 20 cm or 40 cm × 25 cm under dry land or irrigated farming (Emongor et al., 2013; Emongor and Oagile, 2017; Moatshe, 2019; Moatshe *et al*., 2020a). The fatty acid composition of safflower oil was linoleic (54-78%), oleic (11.1-23.4%), palmitic (7.0-16.1%), stearic (2.3-6.3%), arachidic (0-1.93%), iso-stearic (0-1.47%), and iso-oleic (0-1.6%) depending on genotype, plant density, and growing season (Moatshe, 2019; Moatshe et al., 2020a). Safflower oil is high in polyunsaturated and monounsaturated fatty acids which are essential to human diet.

The project also showed that safflower genotypes influence vegetative growth, phenological stages, yield components, seed and oil yield, and seed oil content (Oarabile., 2017; Emongor et al., 2017; Moatshe, 2019; Moatshe et al., 2020b; Emongor and Emongor, 2022). The optimal nitrogen (N) and phosphorus (P) fertilizer application rates to maximize safflower vegetative growth, seed yield and oil content under sandy loam soils of Botswana is 40–75 kg N/ha and 50 kg P/ha depending on genotype, growing site, and season (Mazhani, 2017; Kolanyane, 2022; Kolanyane et al., 2021, 2022).

The results of the projected demonstrated that safflower cake after oil extraction and seeds can be used for livestock feed or used to formulate other livestock feeds since it contains crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) and ash contents which significantly varied between 19.3-22.5, 54.6-61.2, 45.0-50.7, 18.0-20.8, 1.10-1.60%, respectively, depending on genotype and growing season (Phuduhudu et al., 2018; Kereilwe et al., 2020). The safflower seeds mineral content significantly varied between 6.98-7.90 mg/g P, 10.68-12.91 mg/g K, 8.78-10.61 mg/g Ca, 4.45-4.99 mg/g Mg, 90-120 ppm Zn, 70-90 ppm Fe, 40-50 ppm Mn and 90-130 ppm Cu, respectively, depending on genotype and growing season (Phuduhudu et al., 2018; Kereilwe et al., 2020). Significant differences existed in the safflower seed oil content, DM, CP, NDF, ADF, ADL, and ash which varied between 26.13-42.17, 91.9-96.1, 16.3-19.1, 42.6-50.3, 39.7-48, 13.5-20.7, and 0.95-1.41%, respectively, depending on genotype and growing season (Phuduhudu, 2017; Phuduhudu et al., 2018).

The project findings also demonstrated that safflower leaves can be used as vegetables and livestock feed. The safflower leaf DM, CP, ND, ADF, ADL, ash, vitamin C, vitamin B1, vitamin B2, carotenoids, and phenolic compounds significantly ($P < 0.05$) varied between 88.1-91.2, 21.1-29.7, 20.5-26.2, 26.5-32.7, 6.7-10.7, 0.89-1.13%, 8.1-19 mg/100g, 0.02-0.04 mg/100g, 0.05-0.1 mg/100g, 2.5-3.54 mg/100g, and 76-235 mg/100g respectively, depending on genotype and growing season (Phuduhudu, 2017; Phuduhudu et al., 2018; Emongor & Emongor, 2023). The leaf mineral content varied between 3.31-4.95 mg/g P, 56.13-66.54 mg/g K, 10.61-16.51 mg/g Ca, 3.91-4.92 mg/g Mg, 0.51-0.69 mg/g Na, 70-90 ppm Zn, 310-460 ppm Fe, 280-380 ppm Mn, and 6.3-8.3 ppm Cu, respectively, depending on genotype and growing season (Moatshe et al., 2020c). The above nutritional content of whole safflower seed, cake and leaves showed that safflower is an excellent animal feed (Kereilwe et al., 2020). All the safflower genotypes evaluated had sufficient nutritional content to be used as a green leafy vegetable for human consumption, and food and nutrition security (Moatshe et al., 2020c).

The project also showed that safflower genotypes and planting time influence the agronomic traits of safflower, phenology, incidence, and severity of chilling injury (Moatshe et al., 2020b; Korononeo, 2023; Emongor & Emongor, 2023).

The results of the project indicated that phenological traits [days to emergence (8-12), days to flowering (74-117), days to end of flowering (84-126), and days to physiological maturity (99-167)], vegetative growth [height to first branching (13-34 cm), plant height (67-118cm), and number of primary branches/plant (6-20)], yield components [capitula diameter (10-19 mm), number of capitula/plant (11-25), number of seeds/capitulum (13-72), and 1000-seed weight (28-51g), seed yield (1063-6557kg/ha), petal yield (91-300kg/ha) varied with genotype, planting season, plant mineral nutrition and plant density (Mahzani, 2017; Emongor et al., 2015, 2017; Oarabile, 2017; Moatshe, 2019; Emongor et al., 2021; Setshogela & Emongor, 2021; Setshogela, 2024). The carthamidin content (1-7.5%), carthamin content (0.02-0.05%). The mineral nutritional content of the petals was [Ca (424-517 mg/100g), Mg (273-279 mg/100g), K (2214-2328 mg/100g), Na (224-228 mg/100g), Fe (12-17 mg/100g), Zn (2-3 mg/100g) (Emongor et al., 2021; Setshogela & Emongor, 2021; Setshogela, 2024). Proximate variables [moisture content (75-80%), crude fibre (3-5%), crude protein (1-3%), fat content (3-3.4%), ash (5-9%) and carbohydrates (4-10%) (Emongor et al., 2021; Setshogela & Emongor, 2021; Setshogela, 2024). In both summer and winter, safflower genotypes and petal harvest time interacted significantly to influence petal yield, carthamidin and carthamin contents, and dye index. It was concluded that the best genotype to maximize safflower seed and petal yield with high carthamidin and carthamin contents, dye index, mineral nutritional content and proximate variables was Turkey (spineless) (Emongor et al., 2021; Setshogela & Emongor, 2021; Setshogela, 2024). It was also concluded that the best time to harvest safflower petals to maximize seed and petal yield with high carthamidin content which has many health benefits was either at the onset of flowering or full bloom. However, the best time to harvest safflower petals to maximize mineral nutritional content and proximate variables was variable and inconclusive.

The results of this CARP project further showed that 15 insect species belonging to eight orders were observed in safflower. Among the 15 species, ten were pests, four were predators and one was a pollinator (Basiame et al., 2021; Basaime, 2022). The results revealed that the most abundant insect species in summer and winter on safflower plants were *Thrips tabaci*, *Amrasca biguttula biguttula, Macropsis acrotirica* and *Helicoverpa armigera* (Basiame, 2022; Monyame, 2024). *Helicoverpa armigera* and Aphididae species were identified as the most destructive pests of safflower (Basiame, 2022; Monyame, 2024). Order Hemiptera had the highest number of species. Insect pest populations fluctuated along safflower phenological stages and fertilizer application rates, but the most populated stage was flowering (Basiame et al., 2021; Basiame, 2022; Monyame, 2024). The pests fed on all the upper parts (shoots) of safflower plants in the field, with leaves and capitula being the most affected parts of the crop. Even though insects were recorded in abundance, generally the impact of the pests did not significantly affect seed safflower yield in all five genotypes. This was attributed to the compensation ability of safflower plants. Nitrogen fertilizer application to safflower plants led to an increase in insect species population found on safflower plants. Application of 160 and 120 kg N/ha to safflower plants in summer and winter, respectively resulted in overhead insect abundance (Monyame, 2024). On the contrary, increase in P fertilizer application rates to safflower plants led to a decrease in insect population abundance (Monyame, 2024). Safflower plants applied with 60 and 80 kg P/ha had low insect abundance. Interactions of N and P fertilizer applications significantly influenced insect abundance and diversity on safflower plants (Monyame, 2024). The highest diversity index in summer was recorded on genotype Sina (H'=1.47) and the lowest was recorded on PI-537636 (H'=1.32), while in winter the highest diversity was recorded on PI-537636 and Turkey (H'=0.94) and the lowest was H'=0.72 on Sina. The values suggested a non-significant difference in the diversity of insects between genotypes. The Sorensen similarity index also confirmed the similarity between genotypes as the Sorensen similarity coefficient varied from 96% to 100% in summer and varied from 80% to 100% in winter (Basiame, 2022; Monyame, 2024). The temperature indicated a non-significant quadratic correlation with the total population of insects in winter but a positive and non-significant linear correlation with rainfall and relative humidity. In summer, there was a positive and non-significant linear correlation between temperature and total population of insects, a non-significant quadratic correlation with rainfall and a positive curvilinear relationship with relative humidity (Basiame, 2022).

The lowest insect abundance was observed on safflower plants applied with 40N+ 60P and 40N+80P kg/ha in summer and winter, respectively (Monyame, 2024). The highest safflower seed yield was produced by plants applied with 120N+60P and 120N+40P kg/ha in summer and winter, respectively (Monyame, 2024). It was therefore concluded that to maximise safflower seed yield production with minimal insect pest infestation 120N+40P kg/ha should be applied since the insect pests did not cause economic injury (Monyame, 2024).

3.1.2. Other funding

Further funding in safflower research was obtained by the Department of Agricultural Research (Ministry of Agricultural Development and Food Security) from the Japan International Co-operation Agency (JICA) and Government of Botswana (GoB). The JICA project (US $300,000) was researching biodiesel development in various plants including safflower. The JICA project sponsored one PhD student (University of Botswana) with the Principal Investigator (PI) of the safflower CARP project serving as a co-supervisor. The GoB project funded a PhD student, under the supervision of the PI, who investigated the influence of plant density and genotypes on phenology, agronomic traits, oil content, and composition of safflower. The student has graduated, and she is currently the Scientific Officer in the Ministry of Agricultural Development and Food Security, and she is spear heading safflower activities and funding to farmers.

3.1.3 Training of TVET and secondary school students

Ten (10) TVET students from the Kgatleng Brigades were trained in metal work. The students, in collaboration with their Lecturers designed and developed a safflower planter with financial assistance from the safflower CARP as shown in Figure 14. The safflower CARP research team in collaboration with BUAN supplied all the materials needed for the development of the safflower planter. However, the planter was not completed due to transfer of staff involved in the project and completion of students who started planter, therefore there was no continuity. Getting new staff into the project got complicated because they wanted to be paid allowances (US$ 200/month) which the research team rejected because they were government employees. The research team hopes that the Kgatleng Brigades with government support will complete the planter.

Form four and five secondary students (100) of Moeng College (400 km from Gaborone) who are taking agriculture as one their core subjects were trained on safflower cultivation and product development on 9th August 2024. This is part of BUAN's outreach program to the community with the goal to disseminate innovations to the young learners and encourage them to join BUAN.

3.1.4 Training of farmers

In line with the TAGDev development goals of how to transform smallholder agriculture through available knowledge and technologies and to engage under-utilized potential of universities to contribute to agricultural development through the training of quality, entrepreneurial graduates and farmers, the safflower CARP project trained 1800 farmers, nongovernmental organisations, and policy makers in Botswana. A total of 1800 farmers were were directly trained in safflower agronomy, product development and value addition, modern packaging and packaging of safflower products, record keeping, entrepreneurship, and handling and marketing of safflower products (Figure 32). Out of 1855 farmers trained, 26% and 74% were males and females, respectively (Figure 32). At initial stages of training, many of the trainees were women. However, as the project training progressed men observed the benefits of safflower production through increased income their wives and were getting, therefore men started to attend the trainings.

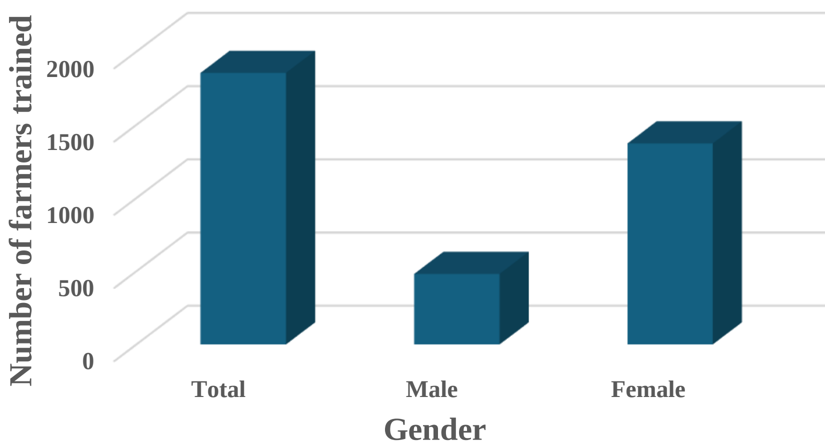

Figure 32. Number of farmers trained

3.1.5 Empowerment of farmers

The safflower CARP project has empowered 168 women who suffered gender-based violence (GBV) during COVID-19 lockdowns in Rakops, Botswana. The women's group is selling safflower vegetables, seeds, herbal tea, and animal feed to the community. The Rakops women's group have registered a co-operative under the Botswana Society Act called **"Saff Energy Initiative Multipurpose Co-operative Society".** The Co-operative wins tenders to supply weekly safflower vegetables to a primary school of 3,500 students. The crop can grow year-round and is able to produce supplies in both the warm wet season and the cooler dry season without supplementary irrigation. This allows farmers to supply safflower products with more consistency which is important to the market outlets. **The safflower project has significantly the social status and disposal income of these vulnerable women that suffered GBV.** The other co-operatives that were formed and grow, develop and sell safflower products include The Kweneng North Horticultural Co-operative Society, African Entrepreneurial Development Agency, and Letsema Co-operative Society.

Lead farmers were empowered through training and became trainers of other farmers at a fee as shown in Figure 8h. Due to the large value chain of safflower, products developed, and marketed, this CARP project has fulfilled its objective of enhancing safflower production and product development with the goal to mitigate the effects of climate change, improve food and nutrition security, social welfare, disposal income of farmers and other stakeholders (Figure 16-23), and build capacity in the safflower value chain using multisector approach.

3.1.6 Promotions and employment

The safflower CARP gave opportunities for lecturers to be supervisors for MSc and PhD students which fed into their key performance areas of research and outreach. These contributed to promotion and fulfillment of performance management system (PMS) requirements of BUAN. Due to research generated publications (MSc and PhD Theses, videos, and papers in refereed journals) and outreach to the community through the safflower CARP, the Co-PI and one other Supervisor were promoted from Senior Lecturer to Associate Professor and Lecturer to Senior Lecturer, positions. All students trained under the safflower CARP project (3 PhD and 4 MSc) are employed by the MoA, except for the one who is finishing her PhD research.

3.1.7 Linkages

The safflower CARP project has created opportunities for multi-disciplinary work and collaboration across departments and faculties within the university (BUAN), between universities (BUAN, University of Botswana, and Botswana International University of Science and Technology), and between the university and other government parastatals (National Agricultural Research and Development Institute and Botswana Institute for Technology Research and Innovation), the ministry of Agricultural Development and Food Security (Botswana), and other universities in SADC (University of Namibia) and East Africa (Jomo Kenyatta University of Agriculture and Technology, Kenya). The development of a safflower planter by the Kgatleng Brigades (TVET institution) has strengthened relations between the BUAN and the TVET institutions. The current CARP project through on-farm research and training of farmers, field days, and workshops has also established much stronger links between the university and the farming community (Figure 8-13, 21). The safflower CARP has also facilitated farmers' access to the university and helped them to access information on both safflower and other horticultural crops more easily through various platforms such as WhatsApp, Facebook, face-to-face through on-farm and BUAN visits. The emerging safflower research is currently demand driven. The farmers are driving the university to engage further.

The safflower CARP has improved the visibility of the university nationally, regionally, and internationally. Safflower CARP has raised the profile of the university with local farming communities through outreach and/or extension services, research, development, and linkages with government agencies and policymakers.

The safflower CARP has also helped the PI to connect with the University of Botswana and Botswana International University of Science and Technology (BIUST) in joint supervision of MSc and PhD students and research in multidisciplinary disciplines such as chemistry and engineering in the development of safflower products such as biodiesel and cooking oil, which leads to sustainability and further development of new products through research.

3.2 Mitigating effects of climate change

The growing of safflower in Botswana is mitigating the effects of climate change, and food and nutrition insecurity caused by low unpredictable rainfall and poor soils because it grows under rainfed conditions in sodic and infertile soils. It produces good yields in environments where other crops such as maize, sorghum, millet, and sunflower cannot grow. Safflower production has improved food and nutrition security, reduced reliance on food imports, and improved income levels of farmers in Botswana through the sale of safflower products such as cooking oil, petals, cut-flowers, vegetable, seed, roughage, and meal. Safflower has improved the livestock sub-sector through the availability of feed (seeds, cake, direct grazing, hay, and silage) and reduced the import bill of livestock feed and vegetables. Safflower cooking oil has the potential to replace imports of olive oil in high-end stores and to provide healthy cooking oil when its extraction is scaled up farmers and other investors or stakeholders.

3.3 Change in government of Botswana policy

The Ministry of Agricultural Development and Food Security (MoA) has changed its policy on the Integrated Support Programme for Arable Agriculture Development (ISPAAD) and developed a new policy called **Temo-Letlotlo programme** in 2022 but was implemented in 2023/2024 ploughing season. The overall goals of the Program are to: 1) Promote household food security by ensuring that micro-scale farmers can produce enough output to contribute significantly to household food consumption needs; 2) Promote commercial production of grain by improving access by crop producers to inputs, credit and other essential services; 3) Promote inclusivity in agricultural production by building rainfed agricultural production systems by facilitating financial access to all commercially-focused farmers; and 4) Improve the social capital base by promoting collective bargaining of rainfed producers. The program targeted 13 crops being sorghum, maize, millet, mung bean, groundnuts, sunflower, **safflower**, cowpeas, sugar beans, wheat, soya bean, fodder and rice. The inclusion of safflower as one of the crops under the program has caused the area under safflower to increase to an estimated 250 ha as of August 2024, with one commercial farmer in Pandamatenga growing 100 Ha of safflower. The goal is to produce cooking oil, animal feed, herbal teas, pharmaceuticals, vegetables, cut flowers, and cosmetics for the country from safflower. In the amended policy, for every 4-ha supported by the government, 1 ha must be safflower. Due this new policy the impact of safflower in Botswana are shown by Figures 33 and 34 (newspaper headlines).

STATE OF SAFFLOWER PRODUCTION IN BOTSWANA

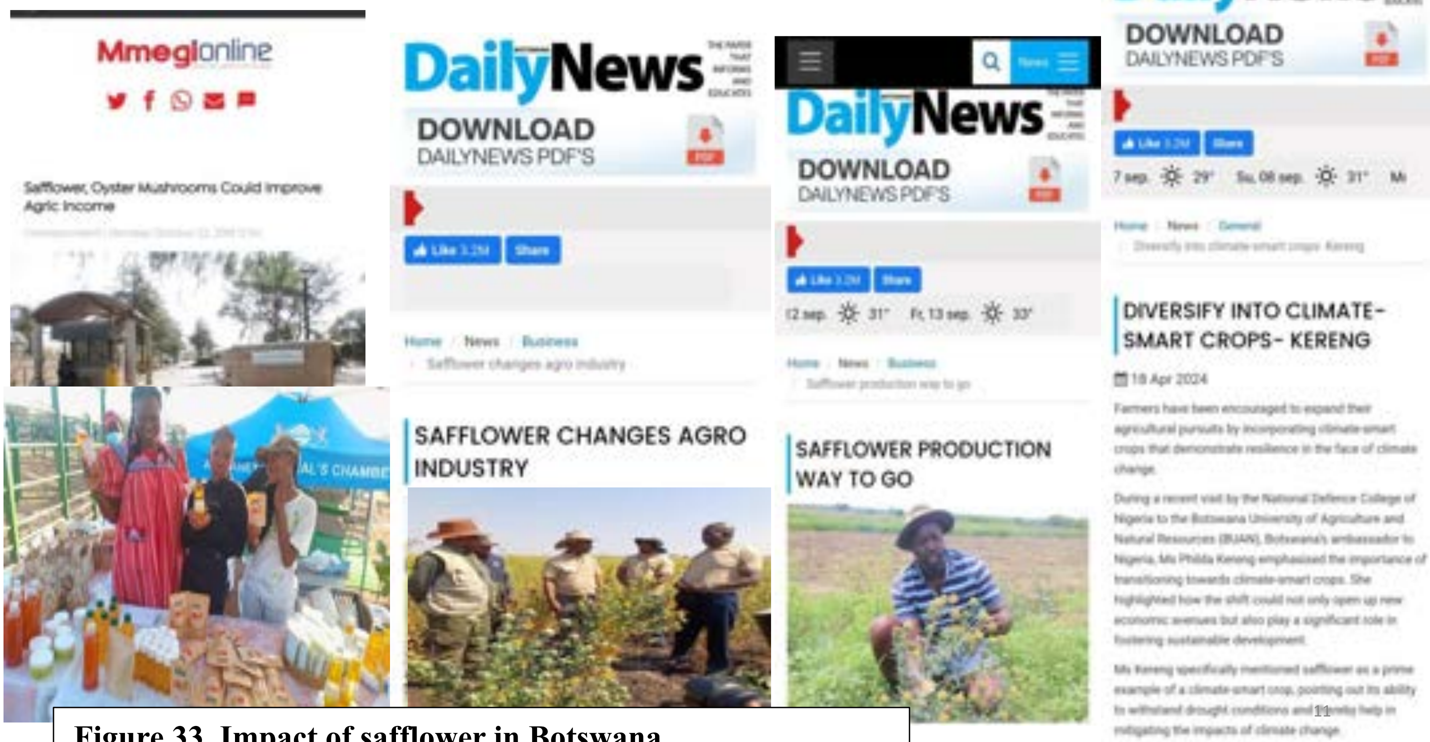

Figure 33. Impact of safflower in Botswana

Daily Business

BUCKLE UP!
Seatbelts Are For Everyone

Safflower changes agro industry

KKT joins mindset change contests

Kennedy Schas

TECHNICAL SERVICES MANAGER

Figure 34. Daily News Paper 1st August 2024

4.0 DISSEMINATION AND COMMUNICATION

Results of the safflower CARP project were disseminated and communicated to different stakeholders consisting of farmers (primary stakeholders), extension officers in Ministry of Agricultural Development and Food Security (MoA), Botswana Agricultural Marketing Board (to buy safflower seed from farmers), researchers, policy makers, financial institutions such as Citizen Entrepreneurial Development Agency (CEDA) and National Development Bank (NDB) for financing farmer-safflower projects, non-governmental organizations (NGO) involved in agricultural development, private seed companies such as SEEDCO, private sector especially manufacturers and the scientific community. Communicationg of project research results to these various stakeholders was done using different communication platforms such as radio, TV interviews and shows (recorded videoes), scientific papers, theses, newspaper publications, book on safflower, workshops, extension brochures, and videos posted in facebook (MoA, BUAN, and Personal pages) and WhatsAPP.

The link below is a video in one of the training sessions as evidence of dissemination.

https://www.facebook.com/watch/?v=1211026239760979&ref=sharing

5.0 Release of safflower cultivars to the farming community

The PI and the research team are planning to release 8 safflower cultivars for safflower production in Botswana by December 2024. The cultivars were evaluated for yield and oil content, and tolerance to drought, salinity, cold, and diseases such as Alternaria leaf spot, rust, root rot and termites. The Cultivars that are to be released by The Botswana of Agriculture and Natural Resources include Kiama Composite, PI 407616 BJ-213 Turkey, PI 537598 SINA USA, PI 30441 BJ-2621 Iran, PI 5376321038-USA, PI 314650 MILUTIN 114 Kazakhstan, PI 537634-1040-USA, and PI 537668-BJ-1085-USA.

Figure 35a. Safflower cultivar PI 537598 SINA USA growing in Pandamatenga, Botswana (100 Ha) rain fed (BUAN staff, farmer and son in hats, 1st August 2024).

Figure 35b. Safflower cultivar PI 537598 SINA USA growing in Pandamatenga, Botswana (100 Ha) rain fed (BUAN staff, farmer and son in hats, 1st August 2024).

6.0 Challenges

The major challenge that the project team faced was the COVID-19 pandemic, especially during the six-month lockdown period in 2020 when program activities could not be implemented. The master's students could not complete their coursework in time which affected the commencement of their research. The other challenge was that farmers expected the project to provide all inputs during on-farm research including irrigation pumps and drippers, fencing the experimental fields, and all agricultural activities (ploughing, planting, weeding, and harvesting). The project supported some of these activities but not fencing and irrigation pumps and related accessories. There was a challenge of government bureaucracy in getting a TVET institution to work with an outside institution which delayed collaboration between the project at the BUAN with the TVET colleges. Reaching out to the government was made possible through support of some of the initiatives undertaken to assist women in difficult circumstances cut off by the pandemic. What was achieved with the women's groups helped to highlight the potential of safflower to both local and national government. This helped to overcome issues related to increasing the profile of safflower, which also triggered policy changes and attracted national media attention. The other challenge was that the TVET Lecturers wanted to be paid US$200 per month to continue with completing the planter which the research team rejected.

7.0 Conclusion

The project implemented and achieved all the set objectives and commercial cultivation of safflower by large scale farmers (30-100 ha) in Pandamatenga region of Chobe District of Northern Botswana has commenced. This CARP project has established networks and built capacity for safflower research, both small-scale and commercial production, product development, extension, marketing, and entrepreneurship with various stake holders including policy makers and investors. This safflower CARP projected has generated scientific information on the physiology, phenology, agronomy, fatty acid composition, processing and value addition of safflower that will enable its commercialization. The multilocation trails led to the selection of safflower genotypes with stable seed yield, oil content, and composition for Botswana conditions. This project has also promoted and created awareness of safflower as a drought tolerant crop to farmers, government extension system and policy makers, NGOs and community-based organizations (CBOs), traders and the formal seed sector (Seed-Co). The Information was specifically targeted to a particular user or set of users and formatted accordingly. The Information was presented through different platforms such as conferences, scientific papers, books, book chapters, TV interviews and documentaries, radio announcements, interviews and documentary presentations, newspaper articles, technical bulletins (brochures), posters, and extension services.

Climate change is predicted to decrease agricultural output in the future because of decreased precipitation and increased land area affected by salinity due to high evapotranspiration induced by high temperatures. Several mitigation and adaptation strategies which are climate smart should be promoted to mitigate and adapt to the deleterious effects of climate change. Growing safflower, a crop with multiple and industrial uses, and adaptable to variable environmental conditions including those found in Botswana and other ASALs has great potential for improving food and nutritional security, disposable incomes, and livelihoods and alleviating poverty of many farmers in Botswana and other ASALs. Safflower has the great potential to industrialize and diversify the economies of countries in the ASALs due to the many products (large value chain) that can be developed and commercialized ranging from healthy cooking vegetable oil, pharmaceuticals, livestock feed, the food industry (leafy vegetables, colouring, herbal tea, and cooking oil), biofuel (biodiesel, ethanol, biogas), the textile industry (dyeing), the cosmetic industry, and the paint industry. These all need further research and investment to be able to fully understand the potential demand and address production and processing constraints. Implementation of effective and specific support policies, technological inputs, pricing, and marketing systems by governments in ASALs into safflower has significant potential to improve food security, nutrition and health, reduce the import bill, and improve disposable incomes and livelihoods alleviating the poverty faced by many farmers.

8.0 Recommendation

The safflower CARP project (BUAN) is releasing 8 safflower varieties (Kiama Composite, PI 407616 BJ-213 Turkey, PI 537598 SINA USA, PI 30441 BJ-2621 Iran, PI 5376321038-USA, PI 314650 MILUTIN 114 Kazakhstan, PI 537634-1040-USA, and PI 537668-BJ-1085-USA) into the local seed systems, to enable a regular supply of reasonably clean seed.

One of the most pressing concerns related to seed supply of modern varieties is how to establish sustainable seed provision systems for commodities that cannot be economically supplied through a centralized, formal seed industry. The seed supply bottleneck primarily affects self-pollinating crops such as safflower. Self-pollinating crops bring little profit to seed companies because of uncertain and fluctuating demand caused by competition from farm-saved seed (safflower seeds). Therefore, individual farmers, farmer groups, businesspeople or local institutions with the necessary resources are to be trained as specialized and commercial seed producers as the next phase of this project. The projects requests RUFORUM to fund this phase of the project. The stakeholders require training in seed production techniques, plant protection, postharvest handling and business skills, and initially they will need regular monitoring and follow-up. Local level seed production is appropriate for sustainability and supports the multiple cultivar release strategy aimed at the needs of small farmer production. The development of decentralized systems of seed production is necessary and calls for forging strong collaborative linkages between seed producers, entrepreneurs, researchers, extension agents, NGOs, credit institutions and the formal seed sector. Notably, a commercial approach is suggested by the research team for sustainability.

The project team also requests RUFORUM to fund the evaluation of the impact of this CARP project on 1) farmers livelihoods, food security and nutrition of consumers of safflower products; 2) disposal income of farmers growing safflower; 3) livestock sub-sector through the availability of feed; and 4) health and well-being of Batswana who use safflower products.

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